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THE JOURNAL OF INTELLIGENT MACHINES

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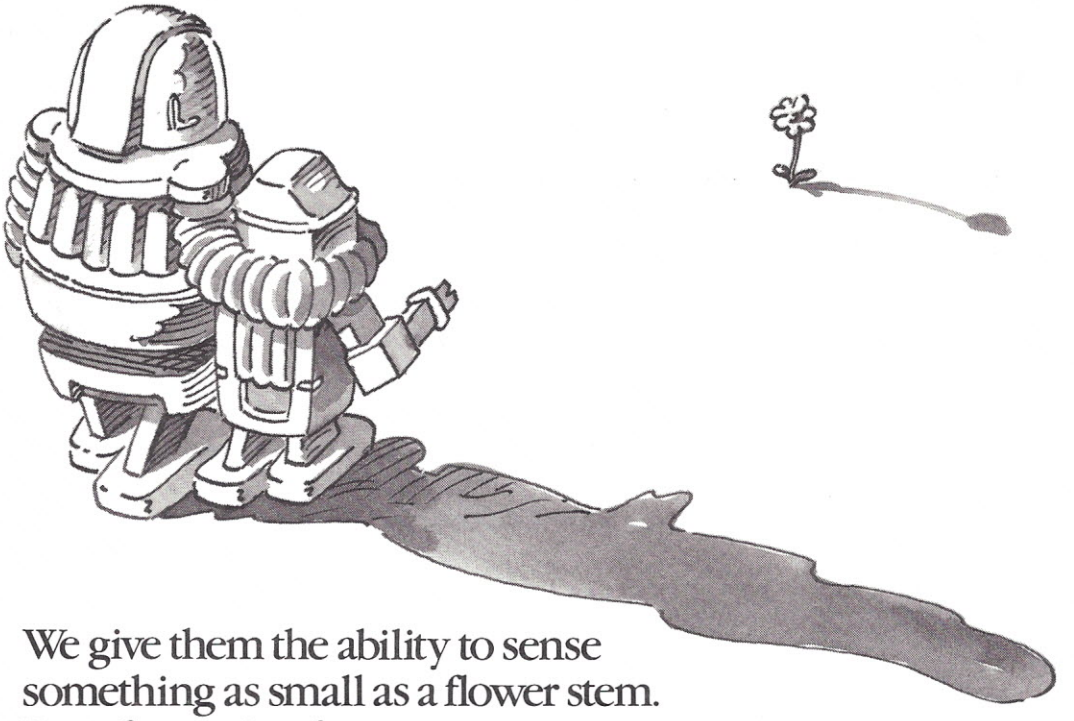

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5/84 RA

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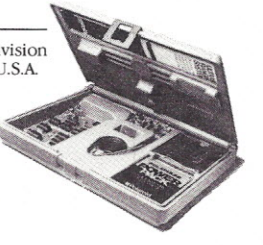

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1984 Rochester Forth Applications Conference

With a Focus on Real-Time Systems

June 6 - 9, 1984
University of Rochester
Rochester, New York

The fourth Rochester Forth Applications Conference will be held at the University of Rochester and sponsored by the Institute for Applied Forth Research in cooperation with the Laboratory for Laser Energetics, College of Engineering and Applied Science, University of Rochester. The focus of this year's Conference is on real-time systems, which includes such areas as process control, data acquisition, smart instrumentation, laboratory systems, robotics, computer vision, spacecraft navigation, music synthesis and voice recognition.

Forth's robotic applications range from Rockwell's contamination-free assembly of inertial guidance systems to JPL's very large base line interferometer used for Voyager spacecraft navigation. Recognizing Forth's integrating role in robotics software and hardware, we are pleased to have three of our speakers discuss their work:

Mr. Ben Ballard, of John Hopkins University, on a bit-slice-based Forth co-processor developed for UV spectroscopy aboard the Space Shuttle.

Ms. Barbara Zimmerman, of JPL and the Palomar Observatory on command and control of the ground-based version of the Wide Field Space Telescope which includes four TI 800x800 CCD arrays.

Dr. Tom Sargent, Io Inc., on a 96 million pixel/sec graphics engine for CAD/CAM and image processing.

Conference Format

Sessions will begin Wednesday, June 6th, and end Saturday, June 9th, and include a group of invited speakers in the area of Real-Time Systems. Submitted papers will be scheduled in platform and poster sessions. There will also be working groups addressing topics of current interest, and demonstrations by participants and vendors. Sessions will be held on the University of Rochester's River Campus.

The registration fee of $300 includes all sessions, activities, meals, and the Conference Proceedings. Full time students may register for $150. Attendees have the option of student dormitory housing at the rate of $100 single/$75 double for five days. Those staying on campus will find a car unnecessary, as there will be a shuttle from the airport and train. A list of nearby motels is also available. For more information, write to Diane Ranocchia, Institute for Applied Forth Research, 70 Elmwood Ave., Rochester, New York 14611 or call 716-235-0168.

Registration Form

Name _____

Address _____

_____

Telephone _____

Are you planning a:
10-20 minute talk? _____ poster? _____ demonstration? _____
If you are, we must have your abstract by April 1st, 1984.

Registration fee: $300 ($150 for full time students) _____
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(If not, you will be assigned one. Non-smoking roommate? yes no)

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Please make checks payable to the Rochester Forth Conference. Mail registrations to: Rochester Forth Conference, 70 Elmwood Ave., Rochester, NY 14611.

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Judith A. Wimberly
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Robotics Age Inc.
174 Concord Street
Peterborough, NH 03458
603-924-7136

Mid-Atlantic, Northeast
CEL Associates, Inc.
61 Adams Street
Braintree, MA 02184
617-848-9306

ROBOTICS AGE—(ISSN 0197-1905) is published monthly by Robotics Age Inc., Strand Building, 174 Concord Street, Peterborough, NH 03458, phone (603) 924-7136. Address subscriptions, change of address, USPC Form 3579, and fulfillment questions to *Robotics Age* subscriptions, P.O. Box 358, Peterborough, NH 03458. Second class postage paid at Peterborough, NH and at additional mailing offices. **POSTMASTER:** Send address change to ROBOTICS AGE, 174 Concord St., Peterborough, NH 03458.

Subscriptions are $24 for one year (12 issues), $45 for two years (24 issues), $63 for three years (36 issues) in the USA and its possessions. In Canada and Mexico, subscriptions are $28 for one year, $53 for two years, $75 for three years. For other countries, subscriptions are $32 for one year surface delivery. Air delivery to selected areas at additional charges, rates upon request. Single copy price is $3 in the U.S., $3.50 in Canada and Mexico, $4 in Europe, and $4.50 elsewhere. Foreign subscriptions and single copy sales should be remitted in United States funds drawn on a U.S. bank.

Address all editorial correspondence to the Editor at *Robotics Age*, Strand Building, 174 Concord Street, Peterborough, NH 03458. Opinions expressed by the authors of articles are not necessarily those of *Robotics Age*. To aid in preparation of acceptable articles, the *Robotics Age* Authors' Guide is available upon request if accompanied by a self-addressed 8½ by 11 inch envelope with first class postage for 3 ounces. Unacceptable manuscripts will be returned if accompanied by a self-addressed envelope with sufficient first class postage. Not responsible for lost manuscripts or photos.

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THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

MAY 1984 VOL. 6 NO. 5

EDITORIAL

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Today's powerful personal computers can be used to develop software for personal robots.

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About the cover: We wish it were that simple. Robert Tinney has imagined a gleaming casting somehow floating above the mold in which it was cast. In the real world of sand casting described in Charles Balmer's article "Backyard Foundry for Sand Casting," results don't necessarily glow and sparkle. A little polish goes a long way. You, too, can make unusual metal parts for your experimental robot designs. In Charles Balmer's article you will find out how he made some of the special castings of Avatar, the cover robot of our January/February 1982 issue of *Robotics Age*.

BPA Membership (SMA Division) Applied for, August 1983

A Need For Standards
But, Standard What?

Standard. 1. A flag, banner, or ensign. 2a. Commonly used and accepted as an authority. 2b. Of average but acceptable quality.

Whenever two or more engineers discuss the current state of technology, the question of standards is invariably raised. Standards are wonderful things. They provide us with mass-producible, repairable equipment. In the world of computers, operating system and programming language standards allow software to be shifted from machine to machine with the certainty that the programs will execute as expected. More importantly, they allow programmers to learn several standard languages which are available on a variety of machines instead of having to learn a dedicated language for each computer. Although so-called standard languages often have slight differences from machine to machine, the overall construction of the language is usually constant.

What about the world of robots? Neither industrial nor experimental robots have yet been blessed with a programming standard. In this month's *Androtext* article, author Johndale Solem observes that to this point, the growth of industrial robots has not been seriously hampered by the lack of programming standards. However, as the use of industrial robots and flexible automation machinery expands, the need for standard programming environments will become vital to acceptance and growth.

The same is true of experimental robots. Present experimental and personal robots rely either on a host computer transmitting control instructions or a limited onboard controller with a simple control language. For example, the Heath HERO 1 uses a control language akin to machine code. The basic control language for the RB5X is Tiny BASIC. Rhino's Scorpion system uses a simple command language. Most of the available robot arms need to be connected to a host computer which provides machine-level instructions.

The question arises, Do we need a standard robot programming language? Is it necessary to create a language which can be used with all types of self-contained experimental robots?

As a comparable example, contrast personal and experimental robot development with the growth of personal computers. Personal robots are in the same stage of relative development as the microcomputers of 1975. These early microcomputers were programmed through the now-primitive methods of teletypewriters, front-panel switches, and paper tape. One of the early software developments which helped coalesce the microcomputer market was the introduction of the CP/M operating system.

Continued on page 40

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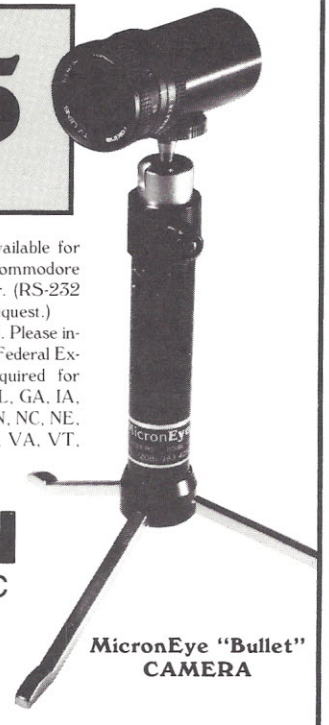

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Letters

Author's Delight

Just got my copy of the March issue—to say that I am pleased is really inadequate. Overwhelmed! is a better word.

I certainly didn't expect to see Armega 33 on the cover. Please convey my thanks and congratulations to Mr. Graves. Just the right amount of stylization, not to mention capturing the swept volume cross-section along with a hint of the polar coordinates on the test table. Real talent.

And an equally superb job on the article itself, headings, captions, photos, and general organization, all of it absolutely first rate.

D. F. Boyd
5337 Taney Avenue
Number 301
Alexandria, Virginia 22304

All we can say is thank you. The decision to use Armega 33 on the cover came as a result of the obviously extensive work you had put into the article. Since a large percentage of our articles are unsolicited (as was your own), many of our covers are created to fit these articles. Jonathan Graves is a relatively new Robotics Age *cover art contributor. You will be seeing more of Jonathan's work in future issues.*

Shape Memory Alloy

First of all I really look forward to receiving your magazine every month. It is a true inspiration.

Secondly, how can I get more information on Shape Memory Alloy, as described in your March 1984 issue, and as used by Hitachi. If nothing else, the address of Hitachi would be a step in the right direction.

Michael Bianco
222 York St.
New Haven, CT 06513

The comment in the March 1984 Sensory Perceptions column about Hitachi's experimental gripper using Shape Memory Alloys has drawn a large response from readers. As a follow-up, we are planning two articles in a future issue. One from Hitachi's Gray Consulting Group, Inc. will describe the actual Hitachi gripper and the research that went into developing the Shape Memory Alloy. A second article from Memory Metals, Inc. will describe the general uses and properties of Shape Memory metals. The Gray Consulting Group, Inc. (the people who developed the Hitachi gripper) can be reached at (212) 888-6996.

Address List

I am interested in obtaining a list of the names and addresses of robot manufacturers and wondered if you had such a list available.

Sincerely,
Lewis B. Jackson, Jr.
50 Barker St.
Mt Kisko, NY 10549

The 1984 Robotics Age Product Guide: A Sourcebook for Educators and Experimentalists *is now available. The Sourcebook contains manufacturer's addresses and descriptions of various robot and robot-related products.*

Armatron Sources

I read your article on the Super Armatron (January 1984) and became very interested in this low-cost robot arm.

As no further information other than the name of the distributor is given, I would like to know how to contact the manufacturer.

Jose Fortes da Gama
Estenge
r. Azeredo Coutinho-296
4100, Porto Portugal

The Armatron was originally distributed in the United States by the Tomy Corporation of Carson, California. The major current supplier of Armatrons in the United States is Tandy/Radio Shack of Fort Worth Texas. Our information indicates that the actual manufacturer is a Japanese company. Unfortunately we do not know which one.

Canadian Information

We have subscribed to *Robotics Age* since its inception and will continue to do so, as we believe this market area will eventually be of significant importance to our company in the future.

Since we are a Canadian Sales Representative Company, we are very interested in the robot marketplace. We would appreciate it if you could somehow summarize or focus on what is happening in Canada relative to robotic activity that you would consider significant. There is no urgency to this request, but a response would be appreciated.

Thank you for your consideration, and we assure you of our continued support.

A. Deskin
Deskin Sales
77D Steelcase Road West
Markham, Ontario L3R 2M4
CANADA

Once again we must turn to our readers for information. A future issue of Robotics Age *will publish any information we receive on Canadian robotics work.*

Reader Impressions

Please enter my subscription for one year to *Robotics Age* magazine. I have been purchasing your magazine from the very first issue at our local computer retailer and I have been very impressed with it. There is a lack of information regarding robotics. My firm is involved in manufacturing. We use several automated welding procedures. Even within the trade, very little information is available to the end user of these devices or the parties involved in the development of these devices. The information which is available is usually provided by the equipment manufacturers. Your publication provides a viewpoint of both the industry and academia. I particularly like the articles which cover case studies of current implementations of various devices.

Regards
Jeff Hallsten, P.E.
Hallsten Supply Co.
PO Box 41036
Sacramento, CA 95841

Calendar

MAY

7–11 May. 1984 Computer-Aided Engineering and Manufacturing Seminars and Exhibition. North Carolina State University, McKimmon Center, Raleigh, NC 27605. Contact: Alice Strickland, NCSU, Division of Continuing Education, Box 5125, Raleigh, NC 27650, telephone (919) 737–2261.

7–11 May. Microcomputers in Control Systems Including Interfacing Methods. Course #5220C. Ottawa, Canada. Contact: George Harrison, The George Washington University, Division of Continuing Education, Washington, DC 20052, telephone (800) 424–9773 or (202) 676–6106.

This course is designed to familiarize participants with the capabilities of microcomputers to replace digital, analog, and electromechanical control elements in control applications. Participants are shown the current state of technology in microcomputers and become familiar with both the economic and technical aspects of the use of such systems as replacements for more conventional control methods. This course is for technicians, engineers, and technical managers who are interested in the applicability, selection, and use of microcomputers, and who want hands-on understanding of applications and interfacing of microcomputers in control systems.

15–16 May. Factory Systems Summit Conference. Chicago, IL. Contact: Lisa Caruso, Seminar Director, The Yankee Group, 89 Broad St., Boston, MA 02110, telephone (617) 542–0100.

The conference, sponsored by the Yankee Group, will provide a framework for addressing current issues in implementation of advanced manufacturing technology. The key discipline is not technology but a tactical approach to managing technology. The conference stresses the importance of planning for implementation and will illustrate successful strategies with examples.

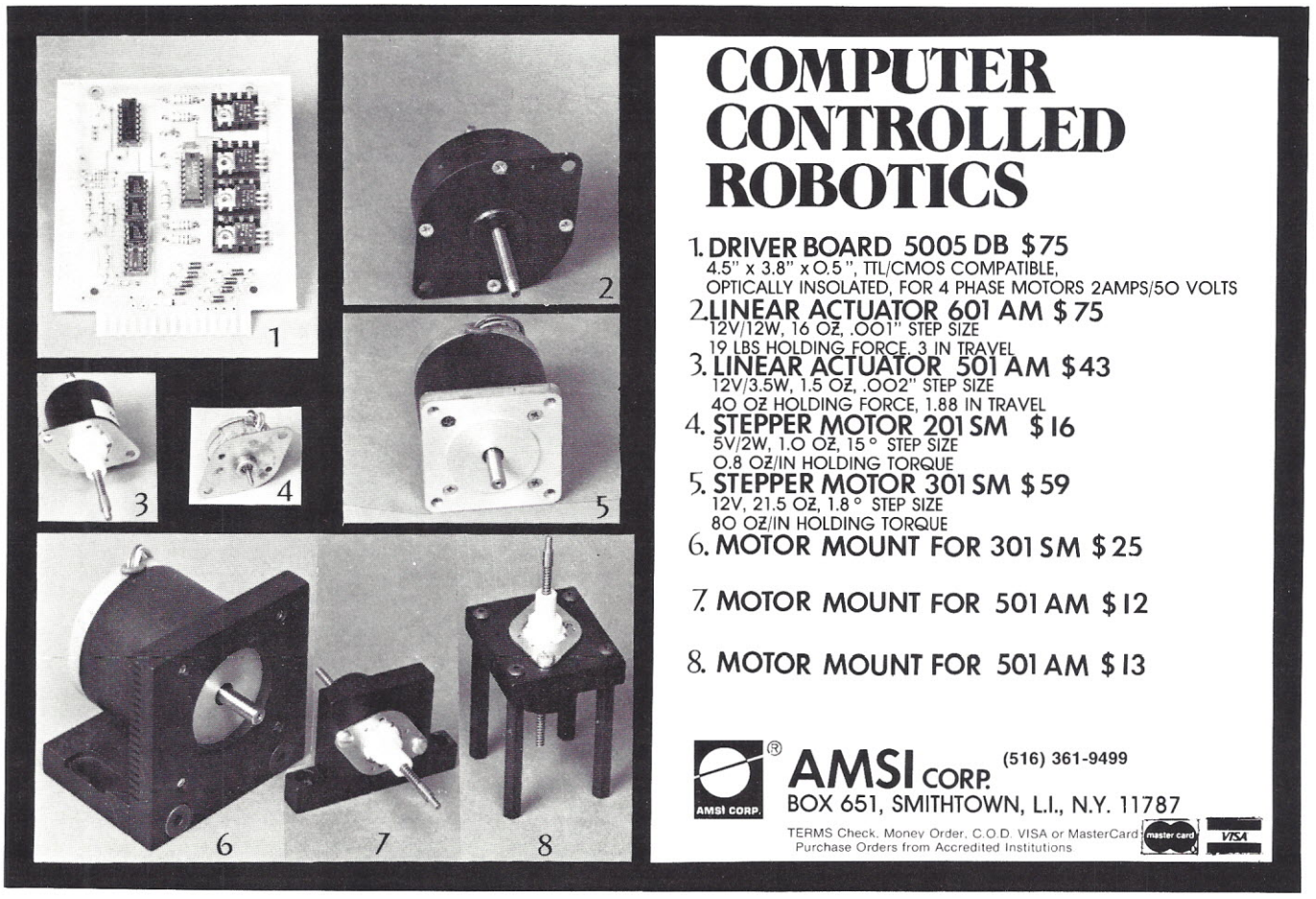
22–24 May. Control Expo 84. O'Hare Exposition Center, Rosemont, Illinois. Contact: Tower Conference Management Company, 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668–8100.

Control Expo is sponsored by *Control Engineering* Magazine. Over 6,000 controls specialists are expected to attend this year's exposition. A comprehensive conference program of 25 technical sessions covers topics such as controlling flexible assembly systems, sensors for adaptive control systems, applications and advances of standalone digital process controllers, fitting robots to the applications, and advances in the control of large batch processes.

JUNE

4–7 June. Robots 8. Cobo Hall, Detroit, MI. Contact: Jeff Burnstein, Robotics Institute of America, PO Box 1366, Dearborn, MI 48121, telephone (313) 271–0778.

The theme for this year's annual Robots show is "Merging Technologies." More than 20,000



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specialists, industrialists, and manufacturing engineers, and executives are expected to attend the four-day event. The conference features more than 80 leading experts explaining new aspects of robot implementation, applications, and research. The exposition will occupy the entire main level and additional exhibit space at Cobo Hall.

19–21 June. 3rd Canadian CAD/CAM & Robotics Exposition and Conference. Toronto International Centre of Commerce. Contact: Hugh F. Macgregor & Associates, 662 Queen Street West, Toronto, Ontario M6J 1E5 CANADA, telephone (416) 363–2201.

This exposition is the major Canadian marketplace for advanced manufacturing systems. Conference topics include: Robotics Justification for Management, CAD/CAM, Robotics Education, Robotics Socio-Economic Considerations, Robotics Engineering, and Robotics Applications.

25–29 June. Computer Vision and Image Processing—8409. University of Michigan. Contact: The University of Michigan, College of Engineering, Engineering Summer Conferences, Chrysler Center, North Campus, Ann Arbor, MI 48109, telephone (313) 764–8490.

With the advent of high-speed computers, processing and extracting information from images has become an important technology. This course presents techniques for processing images and recovering useful information with emphasis on solving problems having a variety of applications.

JULY

9–12 July. 1984 National Computer Conference. Las Vegas Convention Center, Las Vegas, NV. Contact: Trudi Riley, AFIPS, 1899 Preston White Drive, Reston, VA 22091, telephone (703) 620–8952.

Enhancing Creativity is the theme of the twelfth annual NCC. The conference will focus on how the widespread availability of computing resources is altering the office, factory, and home.

23–27 July. SIGGRAPH '84. Minneapolis, MN. Contact: SIGGRAPH Conference Office, 111 East Wacker Drive, Chicago, IL 60601, telephone (312) 644–6610.

This year's SIGGRAPH Conference attendees will be treated to a vast array of technical and exhibit offerings. The program includes up to 30 one- or two-day courses, panels on topical computer graphics issues, a larger number of exhibits, a design arts show, and the premier of the first totally computer-generated Omnimax film.

30 July–3 August. Robot Manipulators, Computer Vision, and Automated Assembly. MIT, Boston, MA. Contact: Director of the Summer Session, Room E19-356, Massachusetts Institute of Technology, Cambridge, MA 02139.

A short course given at MIT to prepare participants for the sophisticated methods soon to be employed in advanced automation. The emphasis is on developing strategies for the solution of problems in sensing, spatial reasoning, and manipulation. The use of existing industrial robots and binary vision systems is also covered.

AUTOMATION
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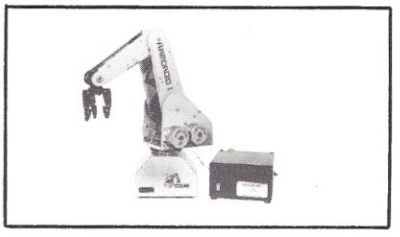
by COLNE



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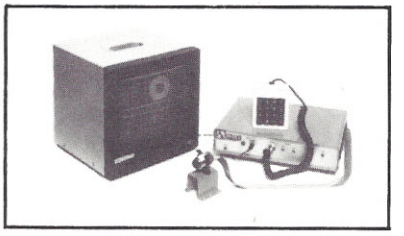

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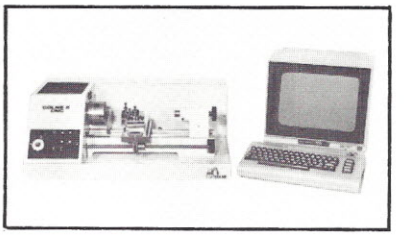

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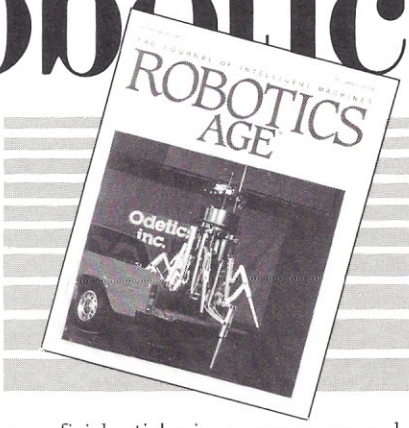

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Calendar

AUGUST

1–3 August. The Computer: Extension of the Human Mind. Eugene, Oregon. Contact: Summer Conference Office, College of Education, University of Oregon, Eugene, Oregon 97403.

This conference, the third annual computer and instructional technologies conference to be sponsored by the Center for Advanced Technology in Education, will focus on the needs of the individual who has become responsible for school and district-level use of computers and other emerging instructional technologies. Both general and special interest group sessions will be supplemented with an extensive vendor hall and film/video theater related to computer technology in education. Pre- and post-conference workshops will be conducted on the educational uses of computers.

5–8 August. Lisp and Functional Programming. University of Texas at Austin. Contact: Robert S. Boyer, University of Texas at Austin, Institute for Computing Science, 2100 Main Building, Austin, TX 78712, telephone (512) 471-1901.

This is the third in a series of biennial conferences on the Lisp language and issues related to applicative languages. Areas of interest include implementation problems; programming environments; large implementations; support tools; architectures; microcode and hardware implementations; significant language extensions; lazy evaluation; functional programming; logic programming; combinators; FP; APL; Prolog; and other languages.

20–24 August. National Conference and Exhibition on Robotics—1984. Melbourne, Australia. Contact: The Conference Manager, Institution of Engineers-Australia, 11 National Circuit, BARTON, A.C.T. 2600, AUSTRALIA, telephone (062) 73-633.

The conference promises to be the most important Australian robotic event held to date. It will have a strong application and education emphasis. Leading Australian robot users, developers, and researchers will present their experience and views on this important high technology area.

SEPTEMBER

25–27 September. International Industrial Controls Conference and Exposition (IIC '84). Philadelphia Civic Center, Philadelphia, PA. Contact: Tower Conference Management Co., 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

Preliminary session titles include: Advances in Information Flow Networks; Highways for Factory Automation; Vision; User Friendly Software for Programmable Controllers; Fiber Optics; and Robotics.

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Backyard Foundry for Sand Casting

Part I: Furnace Design

Charles Balmer, Jr.
929 South Dugan Rd.
Urbana, OH 43078

This is the first of a two-part article describing the construction and operation of a backyard foundry. This first installment presents an overview of the design and construction of a compact, backyard foundry furnace and its operation. Next month, part two of the series will cover making patterns, molds, and an actual casting.

When I was constructing my home-built robot Avatar, I found it necessary to create complex, molded shapes. I used aluminum sand castings for some of the complex structural shapes. While I am certainly no expert, I have, over the years, picked up enough knowledge to make castings suitable for my personal needs. The process itself is not conceptually difficult. All it takes is the right equipment and enough practice to get a feel for making good patterns and molds. While this is not intended to be a construction article per se, it presents enough detail so that anyone with a serious interest can get started building a foundry.

While designing almost any mechanical structure, the designer may face a situation where the use of a part with a complicated shape makes good sense. This may be because the part has to serve several functions; or because aesthetically, the part would look better. Sometimes more strength can be obtained by using one complex shape rather than several simpler shapes that are all attached. If only one part is needed, it could be machined from a block of material, but this wastes material and generally requires the use of expensive metalworking equipment.

The casting process is ideal for making such complex parts for several reasons: the process conserves material; the part can be mass-produced; the material properties can be tightly controlled; and the amount of final machining can be reduced. These are all excellent reasons for making production castings. The overriding reason the experimentalist should consider is that the pattern for the part can be made from materials (such as wood) which are easy to work with and generally don't require the use of expensive equipment. In fact, good quality patterns can be made using nothing more expensive than a pocket knife and a piece of pine.

The use of castings in your robot design can add immensely to its structural integrity, the quality of its appearance, and the ease of construction. It might even open the door to some imaginative structures that would be almost impossible to build any other way.

A variety of casting techniques exist. Each one has a unique property that makes it suitable for a specific purpose. Lost wax casting can give extremely fine detail, but the pattern (or a copy) is destroyed when making the mold. Investment casting is a similar process, but it lends itself better to mass production techniques. Die casting can produce parts which require no machining at all, but this process is beyond the capabilities of the average experimentalist. Sand casting—the process discussed here—is similar to making footprints on the beach. A pattern is made of wood, plastic, plaster, or even metal and is pressed into the sand. The impression left after the pattern is removed is filled with molten metal. Once the metal solidifies, it is removed from the sand, cleaned, and, if necessary, machined.

I will take you through the sand casting process by first describing the construction and operation of a furnace. Next month, part two will show how to make patterns and molds, and an actual casting.

Several companies sell ready-made equipment, but if you are even halfway good at scrounging materials, you can probably build a furnace similar to the one described here for less than $50.00. In fact, there are only a few items (like crucibles, molding sand, silica parting dust, and the furnace core refractory material) that you will have to buy. Searching the hobby magazines will probably reveal two or three companies with foundry supplies for sale.

When sizing the furnace, you will need to know the crucible size that it must accommodate. This may not be an easy decision. Crucibles come in standard sizes, from one inch in diameter on up. Each size is rated by the volume of molten metal it can hold. By some intelligent method, you will have to determine the volume of the largest casting you expect to make and construct your furnace so that it will handle a crucible with at least 50 percent more

Mr. Balmer was the winner of the *Robotics Age* Homebuilt Robot Photo Contest. Avatar, his winning design, was described in the January/February 1982 issue and has since generated considerable interest for both Mr. Balmer and *Robotics Age*.

volume. As an example, the largest four-inch diameter crucible I use holds about 24 cubic inches of metal. This has been adequate for all of the castings I made for Avatar.

Once you decide on an approximate size, make sure your gas supply has sufficient capacity to handle the furnace. The household gas supply should be adequate, but bottled gas may present a problem. For the furnace described here, I use a 20-pound propane tank that has been quite adequate even when melting iron (see photo 1). For a larger furnace, you may have to go to a 40- or 100-pound tank,

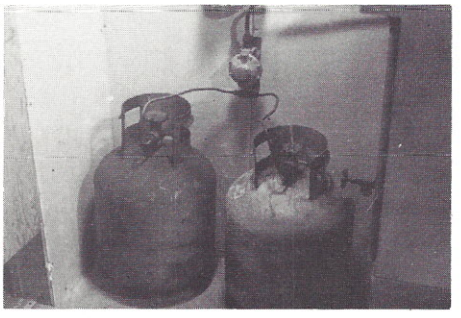

Photo 1. Propane tank setup.

because as gas is released from the tank, pressure drops. If you try using the gas at a rate beyond the tank capacity, the pressure will eventually fall so low that the line regulator will not be able to hold the outlet pressure constant. This effectively limits the furnace capacity.

One advantage of using bottled propane gas instead of the household gas supply is that the foundry can be moved or located wherever it is convenient. Another advantage is that the maximum furnace temperature will be slightly higher using propane as a fuel instead of methane. One disadvantage is that the tanks, regulator, and hoses are expensive.

Furnace Construction. The furnace consists of an inside core, made of refractory material, a surrounding insulating brick structure, and a supporting metal framework. The inside geometry of the core is a cylinder with a tangential fuel/air inlet at the bottom and a tangential exhaust port at the top.

The cylinder diameter should be large enough so that tongs for removing the crucible fit easily around it. Do not make this dimension any larger than necessary since excess furnace volume will increase gas consumption. I used a cylinder diameter of about 5.5 inches at the top with a slight inward taper toward the bottom. This accommodates the largest of the four-inch diameter crucibles I use. The same requirements, with one slight exception, apply to the cylinder height. The bottom of the crucible should rest on the smallest area possible, to minimize the amount of heat lost by conduction. A small pedestal, about 0.5 in. high and one-half the diameter of the bottom of the largest crucible, should be included in the bottom of the furnace. The basic overall dimensions are shown in figure 2. The inside diameter taper is not absolutely necessary for proper furnace operation; it simply reduces the volume that must be heated. The dimensions shown in the figures are for reference only, since the actual dimensions will depend on your needs. The final core dimensions should be such that the wall thickness is never less than 0.5 in.

Two important features of the core are the fuel/air inlet and the exhaust port. While the exact shapes of the ports are not important, the relative sizes are. The exhaust port must be about twice as large as the inlet to reduce backpressure on the blower. The port should also be located at the back of the furnace to reduce the possibility of accidentally touching the hot exhaust. The actual core construction will be dealt with in more detail later.

The core material's insulating properties are not very good. The core's primary function is to structurally withstand the extreme thermal gradients at the center of the furnace. An additional thermal jacket is needed to achieve the high temperatures required to melt iron. Ordinary firebrick—the type used in fireplaces—is adequate. It is also inexpensive and readily available. The firebrick can be used to make the lid for the furnace by bolting several of them

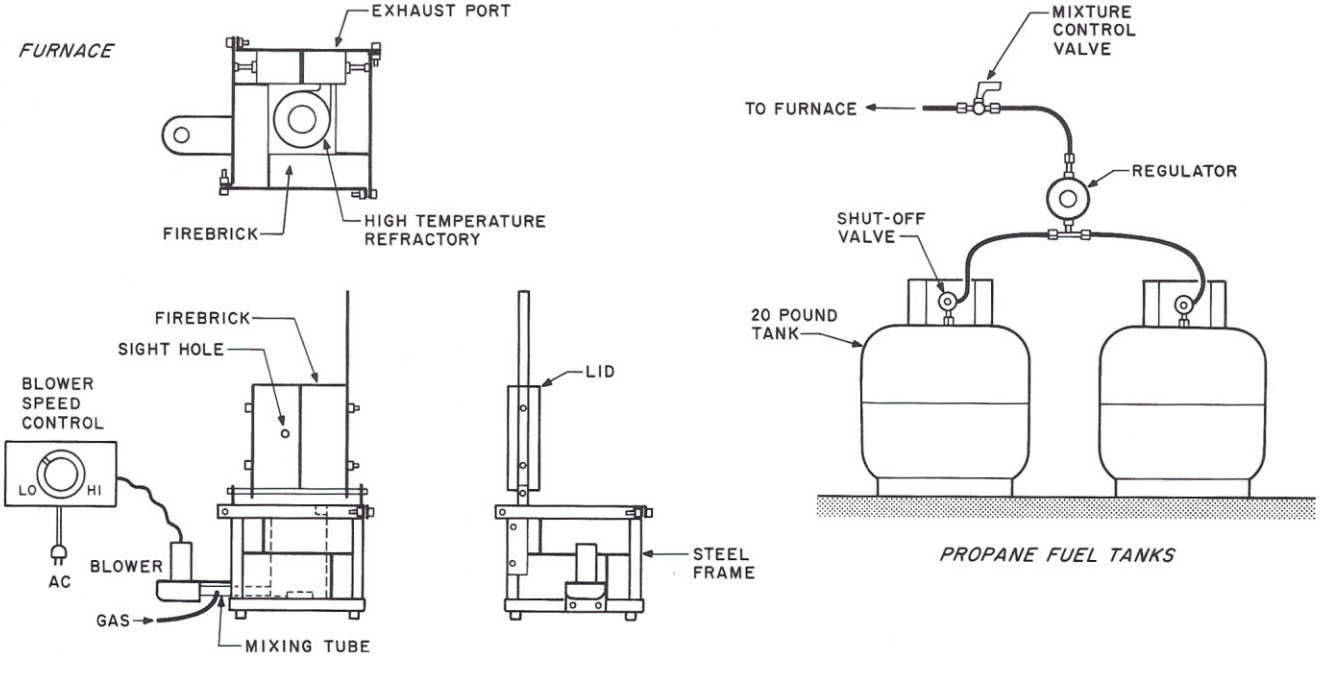

Figure 1. Furnace and piping schematic.

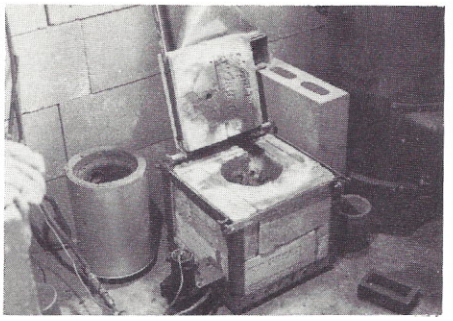

Photo 2. Furnace with lid raised.

together, as shown in photo 2. The sight hole and bolt holes can be made with a masonry drill. The large notches for the mixing tube and the exhaust port can be made using a masonry cut-off saw blade on a circular saw. This should be done outside since a lot of dust is generated. Eye goggles should be worn to protect against flying particles of stone. A skeletal frame is needed to hold the brick and core together. As shown in figures 1 and 2, it can be made from angle iron welded into the proper shape. This whole assembly is then clamped together using strips of 1 by ⅛ in. steel secured by bolts. Because the bricks are not mortared, the furnace can be easily disassembled should the core ever need to be replaced.

The final furnace piece is the burner. It is composed of a gas inlet pipe, a mixing tube, a blower, and a speed controller. The blower is the most important part and should be carefully chosen. It should be a squirrel cage blower with a metal (not plastic) blower housing. While the blower is not exposed to the direct heat of the fire, it may get quite warm from the furnace radiation. The motor on the blower should be of the universal type, AC or DC with brushes, as opposed to an induction type, simply because it will be easier to control its speed. The speed control can be a Variac or a solid-state household dimmer control. If the blower has a low voltage motor, a transformer in the speed controller may be necessary. For the furnace size shown here, the blower capacity would have to be about 30 cubic feet per minute (CFM). Larger or smaller furnaces would require proportionately-sized blowers.

The mixing tube is a piece of steel tubing fastened to the blower outlet and then inserted into the hole provided in the side of the furnace. The mixing tube should not protrude into the furnace chamber, however, since temperatures there can be high enough to melt steel. To prevent air leakage, the tube should be sealed, both to the blower outlet and where it enters the core wall. The fuel/air mixture will be under pressure at this point, and it is important that all of this combustible gas go into the furnace and not leak to the outside. When the furnace is running, combustion will not take place in the mixing tube because of the high gas velocity. The fuel/air mixture will be ignited on entering the core. The fuel inlet pipe is merely a piece of ¼ in. diameter copper tubing brazed into the mixing tube at an angle, as shown in figure 2.

The core is one of the most difficult parts to make. Since the core material (Kaiser MONO P-85) is like stiff clay, there are two ways to form it into the required shape. One way is to make a mold and actually pack the material into it to form the core. This requires making a mold box and a tapered chamber pattern. While this method produces excellent results, it is too time-consuming for just one furnace. The other method is to assemble the frame and firebricks, and force the core material into the cavity by hand. When purchased from the foundry supply company, the material comes in 100-pound blocks, available in solid form or presliced. Get the presliced; it is much easier to handle. Unfortunately, you will probably not be able to buy less than a full block unless they have a box already open.

When packing and forming the material into the desired shape, use a little water to bond the pieces while they are rammed into place. Don't forget the inlet, exhaust port, and pedestal. Once the material has been formed, it should air dry for about a day. This type of refractory must be thermally cured at elevated temperatures. The simplest way to do this is to mount the burner and lid and light a fire in the furnace. Heat the material thoroughly to drive out all the water, and then allow it to cool for about a day. Repeat the procedure until there is no further noticeable escape of steam. The final cure should take the furnace up to full temperature for about an hour. Once the core cools, it will be as hard

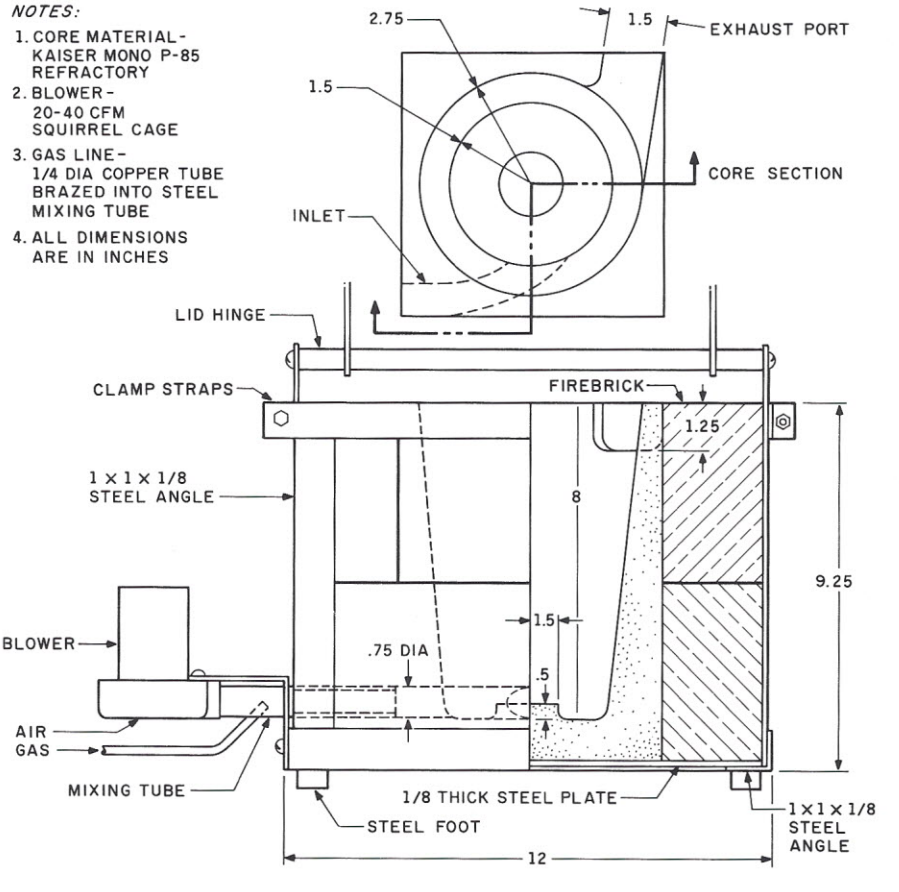

Figure 2. Furnace construction detail—all dimensions are approximate.

as stone, and will have turned from a light grey color to a light tan. At this point the furnace should be ready to use.

Furnace Operation. The basic principles for using the furnace properly are mostly common sense with certain safety precautions. If you want to get it hotter, add more fuel and turn up the blower. But there are a few procedural rules that should be followed for safety's sake.

The most obvious one is that some type of arm covering is necessary. Since the internal temperature of the furnace is sufficient to melt iron, raising the lid exposes the operator to temperatures that can cause severe burns. Heavy asbestos gloves and some of the other necessary safety gear are shown in photo 3. The gloves allow continued exposure to the heat for about 30 seconds before they become too hot to wear. Even with the lid closed, the outside surface temperature of the furnace can cause minor burns.

The furnace should be operated in a well-ventilated area, preferably with some type of forced ventilation, because toxic gases are emitted when the fuel is burned, and some metals, such as lead and zinc, emit small amounts of poisonous gases when melted.

The furnace should be located away from combustible materials.

When pouring molten metal, it is always a good idea to build a little dike of bricks around the area to contain any accidental spills. It is surprising how far and fast a few pounds of molten iron will go before solidifying. Also, be sure to do the pouring on a concrete surface.

Use the following procedure to light and operate the furnace. Leave the gas and blower off, and drop a lighted match into the furnace chamber near the inlet. Stand away while slowly turning on the gas valve. When the gas ignites, a yellow flame about a foot high will rise out of the furnace. Slowly turn up the blower until the flame snaps into the bottom of the furnace. The sound of the flame should be a steady roar. If it is erratic or pulsating, reduce the blower speed until it evens out. At this point you should be able to close the lid. If the fire stops for any reason, shut off the gas supply immediately and open the lid. Allow the burner to purge the furnace for a few seconds before repeating the lighting procedure.

Once you have successfully lighted the fire, let the furnace warm up slowly rather than trying to force it. Rapidly increasing the rate at which the air and fuel enter the cold furnace tends to blow out the flame. This is less likely to occur when the furnace is hot, since the fuel/air mixture is heated more rapidly. Once the furnace is hot you should have an orange to yellow flame rising about two inches out of the exhaust port; if the flame is blue, there is either too much gas or too little air going into the furnace. Adjusting the fuel/air supply will take a little practice and will really only be critical when working the furnace hard in order to melt iron. Altitude and humidity may also affect the proper operation of the furnace at these temperatures.

Photo 3. Safety equipment: gloves, face shield, glasses, fire extinguisher.

If at any time you smell unburned gas, shut everything down until you find the leak. This is particularly crucial if you use propane, since it is heavier than air, and by the time you notice the odor, there might already be a significant concentration built up on the floor level.

Next Month: This concludes the section on furnace design, construction, and operation. Pattern making, mold making, and castings will be presented in the next installment. Other operational and safety considerations will also be discussed.

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A High-Level Language for Personal Robots

Johndale C. Solem
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We are at the dawn of a new era. The dream of mechanical men as personal servants, a dream rooted in antiquity and heightened by the industrial revolution, is about to become reality. Many experts believe that domestic robot servants will appear on the luxury market in the early 1990s, and will become as common as video recorders by the turn of the millennium. As a necessary prelude, we will experience those delightful creatures known as personal robots: kept by some as undemanding pets, by others as enthralling hobbies, and by some for serious research.

Personal robots will serve two valuable functions as a precursor to true domestic robot servants.

First, personal robots will bring robot literacy to our society. You will not speak to your robot as you speak to a human being, any more than you would speak to your dog as you speak to your spouse, or to a child as you speak to a business colleague. For true domestic robots to become useful, we must move partway into their world. A compromise must be reached between their unconscious, pragmatic reality and our cerebral philosophy. The present era of personal robots will provide a social buffer between the machine age and the cybernetic age.

Second, personal robots will catalyze the development of much of the basic software, software architecture, and concepts that are required for the realization of useful domestic robots. This software will not be the exclusive product of professional engineers. Much will be created by individuals in a cottage industry of worldwide proportions. Robot performance of seemingly trivial domestic chores, which we take for granted, will require software of enormous complexity. But the challenge is so rich with fuel for innovation that the algorithms that survive the inevitable evolutionary process will involve the synergistic efforts of thousands of people. A near-term objective of consummate importance is to make the programming of robots accessible to all people.

Androtext, a language developed by Robotronix, Inc., is designed to make communicating with personal robots easy for everyone. It is a high-level language. This means:

- It can be understood with little technical knowledge.
- The same program will work on many different types of robots with minimal modification.

This is a high-minded objective. At present there is no common language for programming industrial robots, and it is unlikely that there will be in the near future. Industrial robots moved into the marketplace too gradually, and local dialects had a long time to develop. There is a chance for personal robots, because they are moving rapidly and local dialects have not become entrenched.

In structuring Androtext, we made two assumptions about the future of robots and computing:

- For the near term, programs for personal robots will be compiled on personal computers and the machine-level instructions transferred to the robot.
- A reasonable home computer will comprise 64 Kbytes of memory, a 5.25 in. disk drive, a monitor, and a printer.

These considerations do a lot to define the size and complexity of a compiler.

The basic components of any robot are:

- A logical processor unit for arithmetic operations, decisions, and control.
- A set of sensors with which the robot acquires information about its relation to the outside world.
- A set of effectors with which the robot changes its relation to the outside world or the state of the world.

In a sense, a computer is a robot whose only sensors are information input devices and whose only effectors are information output devices. The concept of three distinct components leads to a logically

consistent format for a robot language.

To explain Androtext, we will first discuss some of the rules in a semiformal way, using Heath Company's magnificent Hero 1 as a prototype. We will then look at a specific example: how to program Hero to find his way around.

Syntax. A problem with high-level programming languages is that some become so flexible they introduce ambiguities. While flexibility is a desirable goal, it can lead to problems when you try to design a self-documenting language. Androtext is our attempt to create a robot language that is simultaneously natural, flexible, self-documenting, and unambiguous. Therefore, we have introduced certain concepts and constraints.

A basic set of *reserved variables* has been defined. These variables have immutable meanings. Anyone familiar with the Androtext language can read a program and immediately know the meaning of these variables without further documentation.

Only one *separator* exists in Androtext, a blank. Brackets, parentheses, commas, colons, and semicolons have no meaning. All words of a statement must be separated by a blank.

Operands and Operators. There are two kinds of operands: variables, which represent single numbers; and tables, which represent lists of numbers. Any number can also be used to represent a logical value. Since Hero uses an 8-bit microprocessor, each number can be used as a logic vector consisting of eight trues or falses. The term *table* was used instead of *array* because it appears to be more easily understood by nontechnically trained people. The name of a variable may be any length but may not contain numerals, blanks, or special characters other than the hyphen. In general, the more explicit the name, the more easily the meaning of the variable can be understood. For example, DISTANCE-TO-DOOR could be used as a variable and is nearly self-explanatory.

In all operations, tables can be treated as though they were identical to variables. You can use tables in all the same ways as variables, except:

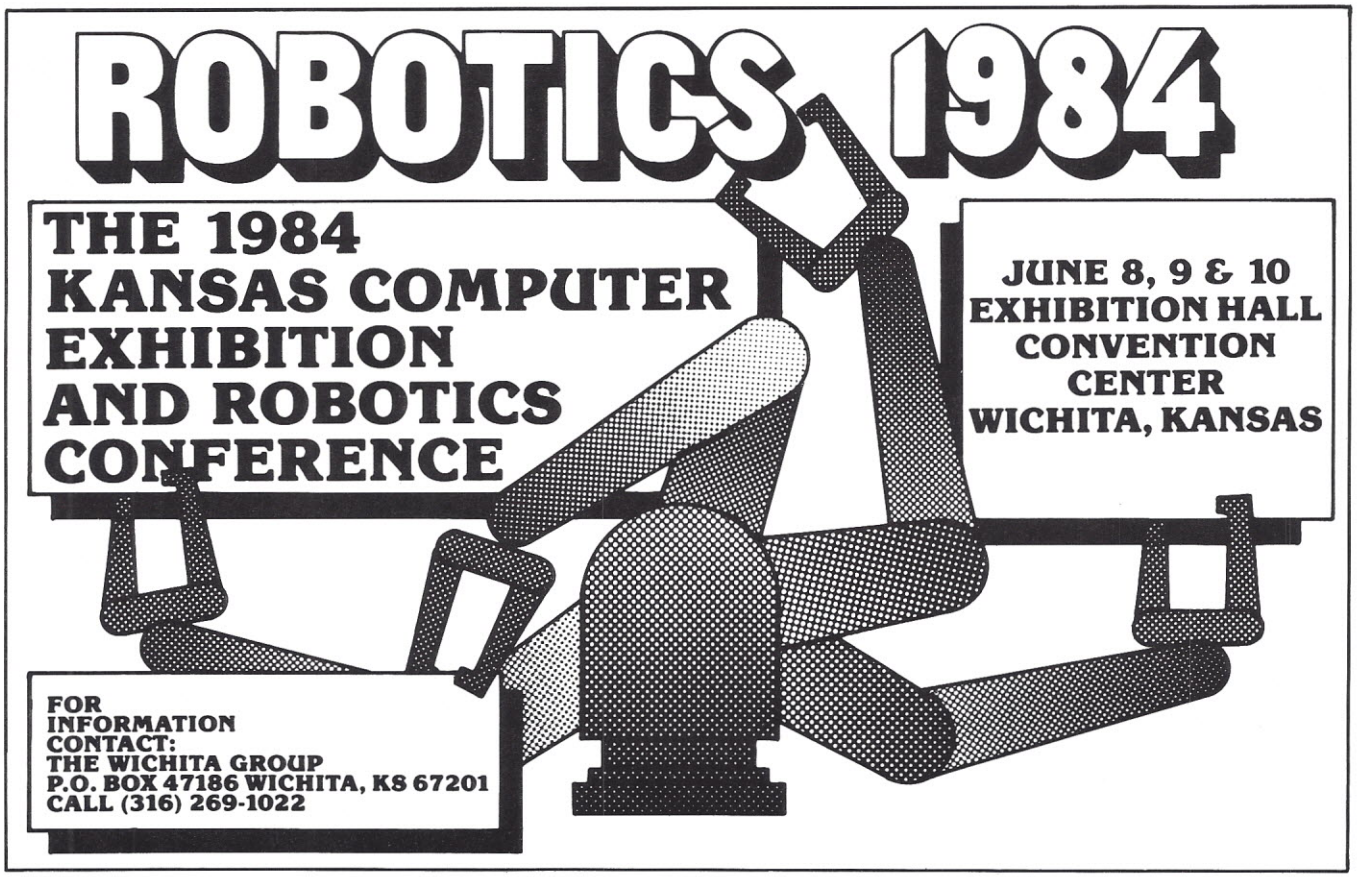
- You must end all table names with a dollar sign, "$".
- You must specify the length of a table before you use it.
- You must assign a number to the reserved variable ENTRY to specify which table entry you want.

The arithmetic operators include the usual addition, subtraction, multiplication, and division. These are shown in the quick reference table. The logical operators include AND, inclusive OR, exclusive OR, NOT, and bit-wise shifts either to the right or to the left. The relational operators include the customary ones found in BASIC. In addition, the IS operator checks the state of an effector for a conditional branch. For example, we could write:

```
10 IF ARM IS IDLE GOSUB 123
```

Passive Effectors. Passive effectors do not physically interact with the robot's environment, but only transmit information. Hero's only passive effectors are its LED display and its speech capability. The Androtext statement

```
10 DISPLAY *HELLO!*
```

causes Hero to display **HELLO!** on the LED console. If you were to write

```
10 DISPLAY *MARY HAD A LITTLE LAMB*
20 DISPLAY *WHOSE FLEECE WAS WHITE AS
SNOW*
```

Hero would display the words of the nursery rhyme one at a time. Because Hero lacks a full alphanumeric display, some of the words would be easier to read than others.

The following program makes Hero display a series of numbers with the word "NEXT" between each number.

```
10 NUMBER = 0
20 NUMBER = NUMBER + 1
30 DISPLAY NUMBER
40 DISPLAY *NEXT*
50 GOTO 20
```

As demonstrated in this following example, Hero can both display and speak numbers.

```
10 NUMBER = 0
20 NUMBER = NUMBER + 1
30 DISPLAY NUMBER
40 SPEAK NUMBER
50 GOTO 20
```

As a demonstration of table and data statements, this next program makes Hero recite the first 20 prime numbers.

```
10 TABLE PRIME$ 20
20 DATA 2 3 5 7 11 13 17 19 23 29
30 DATA 31 37 41 43 47 53 59 61 67 71
40 ENTRY = 0
50 ENTRY = ENTRY + 1
60 SPEAK PRIME$
70 IF ENTRY < 20 GOTO 50
```

The Adaptive Vocabulary. How does Hero know how to speak these words? Phonemes are drawn from a 200-word vocabulary. That vocabulary, however, is constantly changing. If a word to be spoken is not in the vocabulary, the compiler first inspects it for common suffixes: s, es, ed, er, ly, ic, al, ing, est, ful, etc. If the compiler finds one of these suffixes, it looks for the root word in the vocabulary and adds the suffix sound. If it fails to find the root word, the compiler inspects the word for common prefixes: un, de, re, pre, post, anti, etc. If this fails, it tries combinations of prefixes and suffixes. In principle, this makes the compiler capable of remembering more than 10,000 different written words; in practice the number is not this large. If the compiler is unable to find any combination of prefixes, root word, and suffixes that are in the vocabulary, it asks for the correct root word and its phonemes. If the word had no recognizable suffix or prefix, the compiler will only ask for phonemes. For example, if you gave the compiler this statement

```
10 SPEAK *MARY HAD A LITTLE DOG*
```

midway through compilation, the following message would appear.

```
DOG
NOT IN VOCABULARY
PHONEMES?
```

At this point, you would look on page 19 of your *ET-18 Robot Voice Dictionary* and enter "1E3D1C". When the resulting instructions were transferred, Hero would do a respectable job of saying "Mary had a little dog."

If you compiled that same line a second time, you would find that the compiler did not ask you for the dog phonemes. It has remembered them. This does not mean that the compiler increases its vocabulary to 201 words. The compiler throws out an old word and replaces it with "dog." The Androtext compiler uses three factors to decide what word to throw out: recency, frequency, and chance. These are the same factors that affect human memory. The more recently a word has been used, the less likely it will be forgotten. The more frequently it is used, the longer it will be retained. Among the lowest ranking words, the choice of which to eliminate is random.

One of Marvin Minsky's most important contributions to artificial intelligence research is the concept of the *frame*, a method for narrowing a computer's options that makes intelligent dialogue with humans possible. The underlying notion of the Androtext approach to text-to-speech interpretation is that individual programs deal with a rather narrow frame. For example, suppose you are teaching your robot to serve drinks at a cocktail party. All variations in that task are unlikely to require a vocabulary of more than 200 words. When you start to develop the program, you write the previously-prepared vocabulary onto your program development disk. After the normal iterations involved in program development, the vocabulary will have adapted to the vernacular peculiar to a particular task. It is amazing how quickly this adaption occurs. The power of the adaptive vocabulary concept is not obvious until you have tried it.

Elaborate algorithms have been developed for transforming written words into speech. We carefully considered these algorithms before deciding on our method. We chose it not only because it keeps the compiler from becoming unmanageably large, but because it allows the most accurate pronunciation and aural emphasis of words closely related to the frame of a particular task.

Active Effectors. Active effectors are those involving a physical interaction of the robot with its environment, as opposed to the simple transmission of information. Androtext offers great flexibility for the manipulation of active effectors. Because we impose the constraint that each statement may deal with only one effector, the frame becomes sufficiently narrow for the compiler to understand almost any unambiguous statement that would be intelligible to a human reader. Some typical active effector commands follow.

The command to make Hero turn its head to the right range limit is simply:

```
TURN HEAD RIGHT
```

The command to make Hero turn its head right five units is:

```
TURN HEAD RIGHT 5 UNITS
```

This next command makes Hero turn its head to absolute position 180:

```
TURN HEAD TO ABSOLUTE POSITION 180
```

In each of these commands, it would have been possible to tell Hero something else and be equally effective in communicating our intentions. For example, LOOK RIGHT, EYES RIGHT, FACE RIGHT, SCAN TO THE RIGHT, and TURN YOUR HEAD TO BE FACING FAR RIGHT, would have all been interpreted the same way because they are all unambiguous. Here are some examples of phrases that would be properly interpreted:

```
DRIVE BACKWARD
FORGE AHEAD 20 STEPS
RETRACT ARM TO 40
```

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```
EXTEND ARM 14 STEPS
EXTEND ARM QUICKLY TO 45
PIVOT ARM UP AT MEDIUM SPEED
PIVOT ARM TO 75
PIVOT ARM DOWN
PIVOT ARM UP 17 STEPS
ROTATE WRIST LEFT
ROTATE WRIST QUICKLY TO POSITION 44
QUICKLY ROTATE WRIST RIGHT
DRIVE FORWARD FAST
MARCH FORWARD AT QUICK TIME
BACK UP FAST
OPEN GRIPPER
CLOSE GRIPPER TIGHT
SLOWLY OPEN GRIPPER 15 UNITS
TURN YOUR HEAD LEFT 31 STEPS
SLOWLY TURN HEAD LEFT
HEAD TO 62
PULL BACK 3 STEPS
STEER LEFT
STEERING TO POSITION 26 AT SLOW SPEED
TURN STEERING LEFT 14 STEPS
QUICKLY STEER RIGHT
```

It is easy to learn how to communicate with Hero through Androtext. Simply try various phrases. After a while, all the nuances become obvious, and you have developed a common vernacular.

An important aspect of this approach to effector commands is that it allows easy transfer of programs from one robot to another. A successor to Hero may have a completely different set of effectors. However, those commands that have worked for Hero can be interpreted by the new robot. Slight ambiguities that may be arbitrarily resolved by Hero might be interpreted by future robots. Similarly, nuances ignored by Hero may be acted upon by future robots. The essential point is that Androtext is upward compatible.

Two more commands are necessary for the use of effectors. Having given the robot an effector command, we can either wait for that command to complete or continue to execute the program. To continue execution without waiting, a CONTINUE statement must immediately follow the effector command. Any effector that is allowed to continue can be stopped with the HALT command. To resolve ambiguities, the name of the effector to be stopped must follow the HALT command.

Passive Sensors. Passive sensors communicate information about the robot's inner state. They do not explicitly communicate information about the robot's environment. Most important of these are the kinesthetic senses which reflect the state of the active effectors. These sensors, like your own kinesthetic sense and metabolic regulators, are always working. For Hero, the states of the kinesthetic senses are returned in the following reserved variables.

ARM-EXTEND
ARM-PIVOT
WRIST-ROTATE
WRIST-PIVOT
GRIPPER-OPEN
HEAD-ANGLE
STEERING-ANGLE

The passive sensors provide ways of feeding information to your program that would be difficult to acquire by any other means.

Active Sensors. The active sensors are those that the robot must be told to activate, and the inclusion of which entails the use of additional robot memory. Also, most active sensors require additional electrical power. They should be shut down when not in use in order to conserve the robot's energy supply.

The command to activate a sensor is SENSE followed by the particular aspect of the robot's environment that is to be sensed. For example, a typical command would be SENSE LIGHT. The command to shut down a sensor is IGNORE, for example IGNORE SOUND. One or more reserved variables is assigned to each sense. The value of the reserved variable reflects either the number of times that a particular kind of event has been sensed (counting sense) or some quantitative aspect measured by that sense (measure sense). The senses for Hero and their reserved variables are shown in the quick reference table.

The following little program illustrates the use of a measure sense. It causes Hero to display the sound level and to say "Ouch" when the level is too high.

```
10 SENSE SOUND
20 IF SOUND > 100 GOTO 50
30 DISPLAY SOUND
40 GOTO 20
50 SPEAK *OUCH*
60 GOTO 20
```

This next program illustrates the counting sense. It causes Hero to say "Hello there. Good to see you," after he has detected motion 20 times. Hero then resets himself. By waiting until motion is detected 20 times, Hero can be sure that something really is moving, and he is not acting on spurious information.

```
5 MOTION = 0
10 SENSE MOTION
20 IF MOTION < 20 GOTO 20
30 SPEAK *HELLO THERE*
40 SPEAK *GOOD TO SEE YOU*
50 GOTO 5
```

Another illustration of a measure sense is the keyboard. This program causes Hero to recite any number that is typed on the built-in keyboard.

```
10 SENSE KEYBOARD
20 SPEAK KEYBOARD
30 GOTO 10
```

Range is both a measure sense and a counting sense. The reserved variable RANGE returns the distance to an object, while the reserved variable HITS returns the number of times an object is detected.

The commands DELAY, PAUSE, and SLEEP provide real-time control. Each of these commands halts execution for a specified period of time: DELAY in milliseconds, PAUSE in seconds, and SLEEP in minutes. SLEEP shuts down or suspends most of the robot's functions, just as it does for people.

Here is a program which illustrates the use of DELAY. In the science fiction movie *The Day the Earth Stood Still*, the extraterrestrial visitor, Klatu, uses a borrowed flashlight to signal his enormous robot, Gort. Gort has been standing motionless for many days and is facing a wooden fence set up by the local militia. When Gort sees the secret signal flash on the fence before him, he slowly lumbers into action, and follows Klatu into the flying saucer. Our next example program constantly looks for an increase of one unit in light level. If it detects the light change, the program then looks for five similar increases in light level within five seconds.

```
100 SENSE LIGHT
110 FLASH = 0
120 TEST = LIGHT + 1
130 IF LIGHT < TEST GOTO 130
140 TIME = 0
150 TEST = LIGHT + 1
160 DELAY 100
170 TIME = TIME + 1
180 IF TIME = 50 GOTO 110
190 IF LIGHT < TEST GOTO 150
```

ANDROTEXT 1.0 QUICK REFERENCE (Hero 1)

VARIABLES

Any length, but contain no blanks, numbers, or special characters except hyphen (-)

Integer	0 to 255
Logical	True or False

TABLES

Same as variables except end in $
Sum of table lengths < 256

TABLE A$ n	Creates table A$ with n entries
DATA m n o....	Assigns data to table
ENTRY	Reserved variable gives table entry

ARITHMETIC OPERATORS

=	Assigns value to variable
+	Addition
–	Subtraction
*	Multiplication
/	Division

LOGICAL OPERATORS

AND	Logical "And"
OR	Logical Inclusive "Or"
XOR	Logical Exclusive "Or"
NOT	Logical "Not"
X RIGHT Y	Shifts X right Y places
X LEFT Y	Shifts X left Y places

Bits emptied by shifts fill with 0s

RELATIONSHIP OPERATORS

=	Equal
<>	Not Equal To
<	Less Than
>	Greater Than
< =	Less Than or Equal To
> =	Greater Than or Equal To
IS	State of Being

SYSTEM COMMANDS

All system commands may be abbreviated by first two letters

COMPILE	Compiles ANDROTEXT program in memory
LOAD FILENAME?*A*	Loads program A from disk
OPCODE	Changes system to opcode mode
SAVE FILENAME?*A*	Saves program A to disk
TEXT	Changes system to ANDROTEXT Mode
TRANSFER	Transfers opcode to robot

ANDROTEXT EDITING COMMANDS

LIST	Lists entire program
LIST n	Lists line n
LIST n-m	Line n to line m
LIST -m	Beginning to line m
LIST n-	Line n to end
MERGE 2ND FILENAME?*A*	Attaches program A on disk to program in memory
REM A	Comment message A Listed but ignored in compilation
RENUMBER ADDEND?*n*	Adds n to all statement numbers
SEARCH PATTERN?*A* REPLACEM'T?*B*	Searches program for pattern A, displays each occurrence, and permits replacement with pattern B
TIDY 1ST STATEM'T?n INTERVAL?m	Sets first statement number to n, and statement number intervals to m
TYPE TYPE n TYPE n-m etc.	Same as LIST command but outputs to printer

OPCODE EDITING COMMANDS

LIST LIST n LIST n-m etc.	Lists opcode n & m are locations in robot's memory Each line 8 bytes
SEARCH PATTERN?*A* REPLACEM'T?*B*	Searches opcode for pattern A, displays each occurrence, and permits replacement with pattern B
TYPE TYPE n TYPE n-m etc.	Types opcode Each line 16 bytes

ACTIVE SENSORS

SENSE A	Activates sense A
IGNORE A	Deactivates sense A

Sense	**Reserved Variables**
DATE	YEAR, MONTH, DAY
INTERRUPT	INTERRUPT
KEYBOARD	KEYBOARD
LIGHT	LIGHT
MOTION	MOTION
RANGE	RANGE, HITS
SOUND	SOUND
TIME	HOURS, MINUTES, SECONDS
TRIGGER	TRIGGER

PASSIVE SENSORS

Reserved Variables	**Range**
ARM-EXTEND	0-152
ARM-PIVOT	0-134
GRIPPER	0-117
HEAD	0-191
STEERING	0-152
WRIST-PIVOT	0-181
WRIST-ROTATE	0-147

ACTIVE EFFECTORS

Recognizes most unambiguous commands
These are always recognized

ARM	EXTEND/RETRACT
	PIVOT UP/DOWN
DRIVE	FORWARD/BACKWARD
GRIPPER	OPEN/CLOSE
HEAD	LEFT/RIGHT
STEER	LEFT/RIGHT
WRIST	ROTATE LEFT RIGHT
	PIVOT UP/DOWN

ROTATE WRIST LEFT
ROTATE WRIST LEFT 3 UNITS
ROTATE WRIST TO 16

PASSIVE EFFECTORS

DISPLAY *HELLO*	LEDs show "HELLO"
DISPLAY X	LEDs show value of X
SPEAK *HELLO*	Says "Hello"
SPEAK X	Says value of X

MISCELLANEOUS COMMANDS

DELAY N	Delays n milliseconds
HALT A	Stops effector A
INITIALIZE	Initializes motors
PAUSE n	Delays n seconds
ROLL	Starts random numbers
SLEEP n	Sleeps n minutes
STOP	Returns to executive

PROGRAM FLOW

GOTO N	Branches to line n
GOSUB N	Branches to subroutine starting at n
RETURN	Marks end of subroutine. Returns to statement following most recent GOSUB
IF A=3 GOTO n IF A=3 GOSUB n IF ARM IS IDLE GOTO n	If assertion is true, take branch If false, execute next line

GENERAL

Single blank is only seperator

Only relational operations in conditional branches

Arithmetic and logical operations limited to single operator right of =

Continued on page 24

PERSONAL ROBOTS

Peripherals and Software for Personal Robots

MICROMATION proudly presents a peripheral for HEATHKIT'S® HERO-I robot which elevates the robot to a new level of sophistication. We call this peripheral a Voice Command System (or VCS) because it not only consists of a Voice Recognizer (VOREC), but also an advanced level machine Voice Command Language (VOCOL) program for the robot which allows you to program robot movements by voice. Highlights of these two important parts of the VCS are described below.

VOICE COMMAND SYSTEM FOR HERO

VOREC*

VOREC is a powerful, microprocessor controlled, speech recognition board which mounts next to, and interfaces with, our HERO MEMCOM BOARD. VOREC has the following features and specifications:

- Speaker-dependent recognizer with nearly instantaneous word recognition rates.
- Recognition accuracy about 98%.
- Vocabulary of up to 256 words (stored as 16 word groups with 16 words in each group for greater recognition accuracy).
- 16K of onboard static RAM of which 14K is battery backed to retain recognized word parameters during power down.
- RS232 port for receiving commands from, and reporting status and words recognized to, the host (HERO).
- Requires only an external speaker for audio input rather than a microphone. (Allows robot to receive commands from up to 15 feet away.)
- Utilizes high speed (HC) CMOS chips and the new CMOS 65CO2 microprocessor for ultra low power consumption. Complete board consumes an incredibly low 45 ma while active and 1 ma when inactive.
- Speech recognition is accomplished by a software algorithm contained in a 2K EPROM. (Future product updates will require only replacement of this EPROM.)

VOCOL

The VOCOL software is more amazing than the voice recognition hardware. VOCOL is a high level language for the robot which supports both deferred and immediate execution modes. The only difference is in BASIC you "write it," and in VOCOL you "speak it." The software is provided on an EPROM which plugs into a memory socket on our HERO MEMCOM BOARD. VOCOL has the following principal features:

- When first run, the robot talks you through a voice training session.
- Following this training session, you can talk in a program of movements for later execution, or command immediate movement by voice.
- The robot prompts you for a command and when received, repeats it for verification. If verified and in the immediate execution mode, the robot will execute the movement. If in the deferred execution mode, the robot proceeds to write a machine language program in its memory for later execution. When your program of movements is complete, you signify this with a spoken "STOP" command. A spoken "GO" command will then cause the robot to execute the program it wrote in memory. After execution, the robot returns to the command mode.
- Complete instructions and installation manual.

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The Voice Command System manual contains a complete description of how to use the VOREC board under program control from HERO. The 6808 Source Code for VOCOL is available on an APPLE DOS 3.3 disk. This source code is compatible with the SC-6800 CROSS ASSEMBLER.

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- Complete instruction manual and schematics.

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- A disk containing heavily commented 6808 and 6502 source codes for the communications software. These source codes are compatible with the S-C MACRO ASSEMBLER and the S-C 6800 CROSS ASSEMBLER available for the APPLE from the S-C SOFTWARE CORPORATION or MICROMATION. Programs developed using the S-C 6800 CROSS ASSEMBLER can be immediately downloaded and run on the robot using this product and our HERO MEMCOM board. The S-C MACRO ASSEMBLER and 6800 CROSS ASSEMBLER are required when using this disk.

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- A Z-80 to 8086 translator
- 64 page user manual
- 4 linkers included:
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  - –CPM/86 produces .CMD file
  - –Pure object code generation
  - –Object code and address information only

Linker features:

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- Submit mode invocation
- Code, Data Stack and extra segments
- Handles complex overlays

- Written in assembly language for fast assemblies.

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- an 8080 to Z-8000 Source Code Translator
- Z-8000 Macro Cross Assembler
- Linker and Loader
- COM to Hex File Converter
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The Translators provide Z-8000 source code from Intel 8080 or Zilog Z-80 source code. This source code expansion is from 2% to 11%. The Translator outputs a worksheet and a Z-8000 source file. The worksheets show each line of 8080 Z-80 code, with notes to help the programmer to optimize performance, and further lower code expansion. It even comments lines it adds! The Z-8000 source code used by these packages are the unique 2500AD syntax using Zilog mnemonics, designed to make the transition from Z-80 code writing to Z-8000 easy.

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	Z-80 CP/M®	ZILOG SYSTEM 8000 UNIX	IBM P.C. 8086/88 MSDOS	IBM P.C. 8086/88 CP/M 86	OLIVETTI M-20 PCOS
8086/88 ASM			$99.50	$99.50	
8086/88 XASM	$179.50	$750.00			$179.50
Z-8000™ ASM		750.00			299.00
Z-8000 XASM	179.50		179.50	179.50	
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Z-80 XASM		500.00	$99.50	$99.50	$99.50
Z-8 XASM	99.50	500.00	$99.50	$99.50	$99.50
6502 XASM	99.50	500.00	$99.50	$99.50	$99.50
6800,2,8 XASM	99.50	500.00	$99.50	$99.50	$99.50
6801,03 XASM	99.50	500.00	$99.50	$99.50	$99.50
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Continued from page 20

```
200 FLASH = FLASH + 1
210 IF FLASH < 5 GOTO 150
220 DISPLAY *HELLO KLATU*
230 HALT DISPLAY
240 GOTO 110
```

Using logic vectors and the shift function, you can easily alter this program to watch for a secret code.

The random number generator permits the robot to make arbitrary decisions on the basis of probability. It is initialized with the command ROLL (for "roll the dice"). The reserved variable RANDOM contains a new random number each time it is used.

The following program combines the random number generator, the range sense, a conditional branch, and the delay function in such a way that, if Hero either detects an obstruction less than 50 cm away or has his drive motor stopped for some reason (like running into an object that his sonar cannot detect), he will back up and turn right or left with equal probability.

```
100 SENSE RANGE
110 ROLL
120 SLOWLY GO FORWARD 10
130 CONTINUE
140 N = 0
150 IF DRIVE IS IDLE GOTO 120
160 IF RANGE < 50 GOTO 200
170 DELAY 50
180 N = N + 1
190 IF N < 25 GOTO 150
200 IF RANGE < 10 GOTO 170
210 BACK 15
220 STEER LEFT 70
230 IF RANDOM > 127 GOTO 260
240 GO BACKWARD 10
250 GOTO 270
260 GO FORWARD 10
270 STEER RIGHT 70
280 GOTO 120
```

David Heiserman calls this an alpha-level program. The probability with which Hero turns left or right is not influenced by experience. It is easy to modify this program to contain tables of experience and inhibition based on the success or failure of previous responses. That would be called a beta-level program. A program that could make generalizations would be called a gamma-level program.

Getting Around.

Christopher Columbus
didn't have a compass
didn't have a measure
to help him find his way.
—English nursery tune.

If a robot's sensors include a compass to maintain a precise sense of direction and a nonslipping transport mechanism to provide a precise measure of distance, the problem of getting around can be simplified. But Hero does not have a compass and he doesn't have a very good measure. So what can we do to help him find his way?

Hero can follow walls. We found wall following to be very successful when Hero was finding his way around an office building. The following Androtext program makes Hero follow a wall with a clearance of about a foot, plus or minus a half inch.

```
100 SENSE RANGE
110 TURN HEAD TO 40
120 SLOWLY MOVE FORWARD 7 STEPS
130 IF RANGE < 30 GOTO 160
140 IF RANGE > 31 GOTO 180
150 GOTO 120
160 STEER RIGHT 10 UNITS
170 GOTO 190
180 STEER LEFT 10 UNITS
190 SLOWLY MOVE FORWARD 2 STEPS
200 STEER TO 73
210 GOTO 120
```

The best way to pick up position benchmarks is to have Hero carefully measure each intersection or doorway as he goes by. The following program allows Hero to follow a wall on his left until he reaches an intersection. He then backs up, carefully measures the edge of the opening, then moves into the opening, turns left, and proceeds.

```
100 SENSE RANGE
110 TURN HEAD TO 40
120 SLOWLY MOVE FORWARD 4 STEPS
130 IF HITS = 0 GOTO 250
140 HITS = 0
150 IF RANGE > 100 GOTO 270
160 IF RANGE < 30 GOTO 190
170 IF RANGE > 31 GOTO 210
180 GOTO 120
190 STEER RIGHT 10 UNITS
200 GOTO 220
210 STEER LEFT 10 UNITS
220 SLOWLY MOVE FORWARD 2 STEPS
230 STEER TO 73
240 GOTO 120
250 DELAY 300
260 IF HITS = 0 GOTO 140
270 DELAY 300
280 PULL BACK 1 STEP
290 IF RANGE < 60 GOTO 270
300 IF HITS = 0 GOTO 270
310 HITS = 0
320 GO FORWARD SLOWLY 12 STEPS
330 SLOWLY STEER LEFT 70
340 SLOWLY GO FORWARD 15 STEPS
350 SLOWLY STEER TO 73
360 GO FORWARD 30 STEPS
370 GOTO 120
```

This program makes Hero negotiate as many left turns as he encounters until he reaches a final obstacle. If you have followed this carefully, you will realize that he could decide either to turn left or to dead reckon across the intersection and proceed. This decision could be made by a single bit in a logic vector that described the course from one room to another.

No one ever did anything for only one reason.
—Leo Szilard (1898-1964)
Hungarian-American physicist.

Szilard's statement was specifically directed to the functioning of a human brain. There is a school of thought that believes that the human brain is highly multiplexed and every activity has a host of motivations. A combination of this and the uncertainty principle has been suggested as the source of consciousness. On the more mundane level, to keep Hero from getting lost, it is best to give him several navigational tools. The easiest is a sense of distance. A variable keeps track of how far Hero has gone, and calls an error routine if the distance traveled before finding the next benchmark is much greater than expected.

The Androtext subroutines in listing 1 illustrate this technique. Subroutine 100 is called by the main program, which wants Hero to go down the left wall of some maze, and stop at some distance after one of the intersections. At each intersection, the decision to proceed, turn left, or go to a specified distance and stop, is drawn from the table LOGIC$. The table DISTANCE$ contains the maximum distance Hero can travel in pursuit of a benchmark before calling the error routine. The last entry contains the distance beyond the last benchmark at which Hero should stop. A value for ENTRY is passed from the main program. Subroutine 1000 executes a left turn, and subroutine 2000 dead reckons across the intersection. Branching to line 450 either brings Hero to a halt at his

destination or goes into the error routine. For this illustration, the only function of the error routine is to make Hero plaintively cry, "Help me, help me..."

If we write another similar set of subroutines, but with right and left interchanged, we could make Hero reverse his course using the same LOGIC$ and DISTANCE$ tables by decrementing, rather than incrementing, the reserved variable ENTRY.

Every exit is an entry somewhere else.
—Tom Stoppard
"Rosencrantz and Guildenstern are Dead"

The LOGIC$ and DISTANCE$ tables can contain complete information on how to get from any room to any other in an office building or in a house. A third table could be supplied to specify which tracks to take when exiting one room to enter another. Such a table need contain no more information than the value of ENTRY at which to start, and the subroutines to call. The benchmarking technique works as well applied to obstacles in a room as it does applied to intersections in a hallway.

The Editor. Androtext is supplied with a built-in editor. Certain difficulties attend any language in which each statement is numbered. Most programmers would prefer to prepare their programs in discrete routines or subroutines which are individually tested and finally combined into one program. This is difficult in BASIC because of the sequential numbering. The Androtext editor contains a routine called Renumber which allows you to add a number to all of the statement numbers. Naturally, the same number is added to all branches. A second routine called Merge allows you to attach a file that is on disk or tape to the file in memory. Thus, the process of preparing a program as individual subroutines, testing them separately, and then merging them together, is simplified.

A second problem is that no matter how well you plan your program, inevitably you find that you want to squeeze new statements between statement numbers where there are simply not enough numbers available. The Androtext editor supplies a routine called Tidy which allows you to spread the intervals between your statements. Tidy also makes your entire program easier to read.

Androtext for Everyone. At this writing, we have Androtext compilers available for the Commodore 64, the Radio Shack 64K Extended BASIC TRS-80 Color Computer, and the Atari 800XL. If you have a corresponding disk drive (Commodore VIC 1541, TRS-80 Color 2 Disk, or Atari 1050), you can use the adaptive vocabulary while developing your programs.

A hardware adaptor is supplied with the Androtext compiler for connecting the computer to Hero's experimental board. We also supply a cassette tape containing transfer software, which must be loaded through Hero's TAPE IN port. The adaptor requires a Centronics parallel printer interface. To operate the compiler, you

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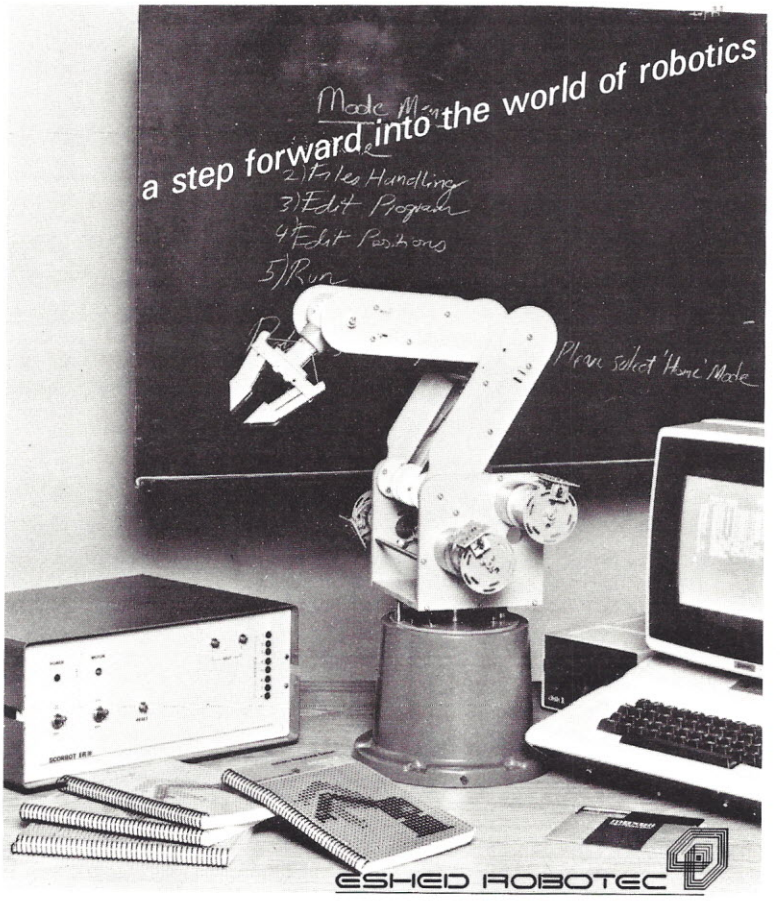

need only disconnect your printer and connect to the adaptor. Cards will be available for those who do not have Centronics interfaces.

By the time this article is published, we should also have versions for the Apple IIe, the Zenith Z-100, and the IBM PC. This winter we will have Androtext versions available for other personal robots as well as Hero.

Things to Come. Over the next several months, we plan to publish a variety of programs written in Androtext. These will be in the public domain for general use. The name Androtext is not copyrighted, nor is the basic structure of the language. While our compilers for Hero are copyrighted, we encourage others to compete with us and market Androtext compilers of their own. Our principal concern is to obtain one common high-level language for all personal robots. This will do a great deal to accelerate the development of true domestic robots. That is to everyone's interest.

We are concerned that the present momentum be maintained, and this emerging technology be brought to fruition without interruption. This has not always been the case with new technology. The first home video recorders were marketed in the mid 1950s. The technology all but died out. It recurred briefly in the late 1960s but did not really mature until the late 1970s. Similarly, microwave ovens were available in the early 1950s, but were not accepted until the late 1960s. Mahlon Loomis demonstrated radio shortly before the Civil War, but it was not taken seriously until after the turn of the century. Personal computers, on the other hand, enjoyed a steady increase in popularity from their inception. This is the exception, rather than the rule.

We believe that establishing a common language for all personal robots will do much to catalyze the inexorable rise of this technology to the fulfillment of an ancient dream.

```
100 REM SUBROUTINE TO FOLLOW
110 REM LEFT WALLS TO DESTINATION
120 REM USES LOGIC$ AND DISTANCE $
130 TURN HEAD TO POSITION 40
140 STEP = 0
150 SLOWLY MOVE FORWARD 4 STEPS
160 STEP = STEP + 2
170 IF STEP > DISTANCE$ GOTO 450
180 IF HITS = 0 GOTO 310
190 HITS = 0
200 IF RANGE > 100 GOTO 330
210 IF RANGE < 30 GOTO 240
220 IF RANGE > 31 GOTO 260
230 GOTO 150
240 STEER RIGHT 10 UNITS
250 GOTO 270
260 STEER LEFT 10 UNITS
270 SLOWLY MOVE FORWARD 2 STEPS
280 STEER TO 73
290 STEP = STEP + 1
300 GOTO 150
310 DELAY 300
320 IF HITS > 0 GOTO 190
330 DELAY 300
340 PULL BACK 1 STEP
350 IF RANGE > 60 GOTO 330
360 IF HITS = 0 GOTO 330
370 HITS = 0
380 ENTRY = ENTRY + 1
390 IF LOGIC$ = 1 GOSUB 1000
400 IF LOGIC$ = 2 GOSUB 2000
410 GOTO 140

450 IF LOGIC$ = 3 GOTO 950
460 SPEAK *HELP ME*
470 GOTO 460

950 SPEAK *HERE I AM*
960 STOP

999 REM SUBROUTINE TO DEAD RECKON ACROSS INTERSECTION
1000 GO FORWARD SLOWLY 70 STEPS
1010 RETURN

1999 REM SUBROUTINE TO EXECUTE LEFT TURN
2000 GO FORWARD SLOWLY 12 STEPS

2010 SLOWLY STEER LEFT 70
2020 SLOWLY GO FORWARD 15 STEPS
2030 SLOWLY STEER TO 73
2040 GO FORWARD 30 STEPS
2050 RETURN
```


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A real-time program for controlling a device such as Armega 33 is, however, an entirely different matter. The crunch comes when the computer is asked to accurately count a series of rapidly recurring events—in this case, the feedback pulses from the counter switches, activated by the cams fastened to the servo lead screws.

It was apparent from the outset that steps would have to be taken to gain additional computational speed from the computer. The most obvious step would have been to write the control programs in Z-80 assembly language. On the other hand, I wanted to retain the simplicity, convenience, and flexibility of the BASIC programming language if possible. The original Zilog Z-80 central processing unit chip for the Tandy Model I has a very modest clock rate of 1.77 MHz. In addition, the Microsoft BASIC language provided in a read-only memory (ROM) is an interpreted implementation. The two available alternatives to assembly language programs were a BASIC compiler and the installation of a Z-80 chip capable of running at a faster clock rate. I hoped that these measures would be sufficient to provide the necessary speedup, and indeed they were.

Two BASIC compilers were tested and the faster of the two, ACCEL I by Southern Software of England, turned out to be the simplest (ACCEL I is available from Allen Gelder Software of San Francisco). ACCEL I is an integer-only compiler, which, for the type of simple arithmetic statements found in control programs, increases the speed of execution over the BASIC interpreter by a factor of 15 to 18 times. I also replaced the standard Z-80 processor with a Z-80B chip which can run at a clock rate of 6.0 MHz. The Z-80B was part of the Sprinter I kit provided by Holmes Engineering of Salt Lake City. Due to the speed limitations of other components in the TRS-80 Model I, it cannot fully meet the 6.0 MHz clock rate, but does function at an effective rate of about 4.1 MHz, 2.3 times the original rate. Between the BASIC compiler and the faster Z-80 chip, the overall rate of execution is almost 40 times that of the original BASIC interpreter.

This speed increase is fortunate since early experiments with the original BASIC interpreter indicated that it could not reliably count more than five counter pulses per second. The present configuration counts well over 100 pulses per second. The highest counter pulse rate at present is about 40 per second from the body rotation servo, which uses a six-lobe cam to activate the counter switch.

Thus, the present program speed is adequate for handling the counter pulse feedback rate from any servo motor. It is not sufficient, however, to monitor simultaneous feedback from several servo motors. As a result, present programs for Armega 33 are written in single element movement sequences. This is not as limiting as it may first appear. Most operating program sequences tend to contain one or two long moves and a number

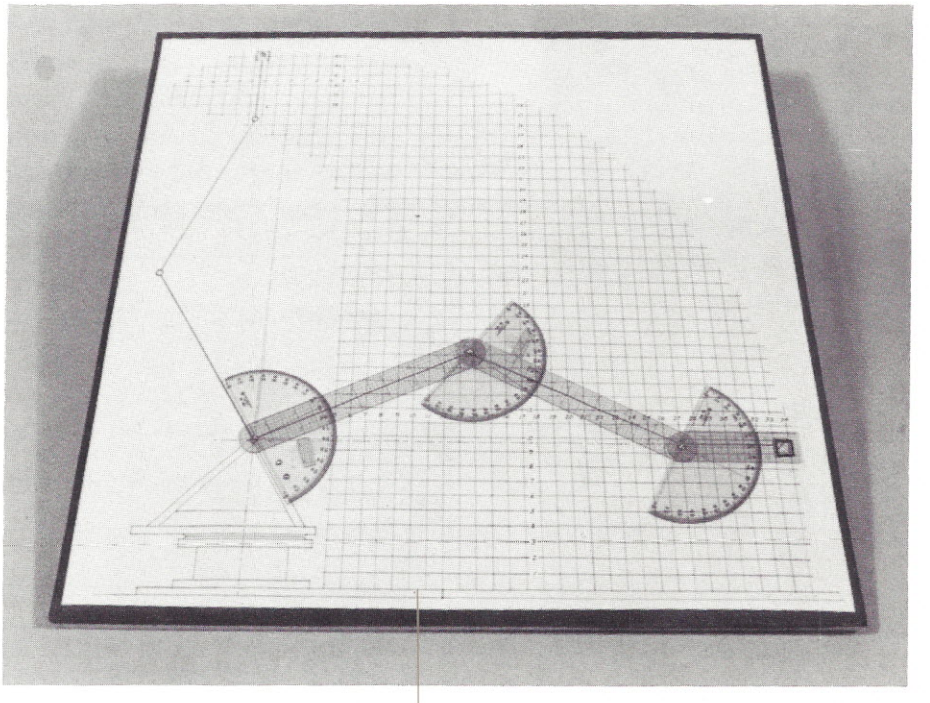
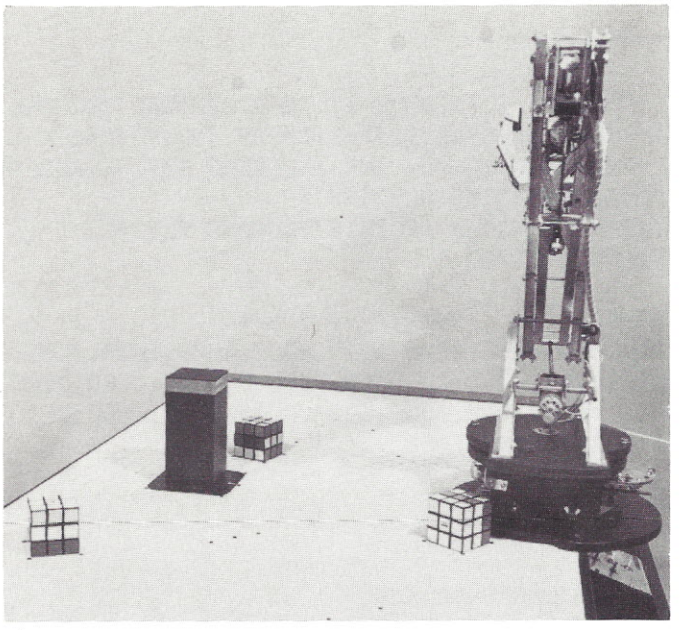


Photo 11. Simulator board. A half-scale model of the bicep, forearm, and hand element of Armega 33. The simulator is used for quick determination of the interelement angles and the corresponding servomotor counts required to reach a desired position of the gripper pads, starting from the home position.



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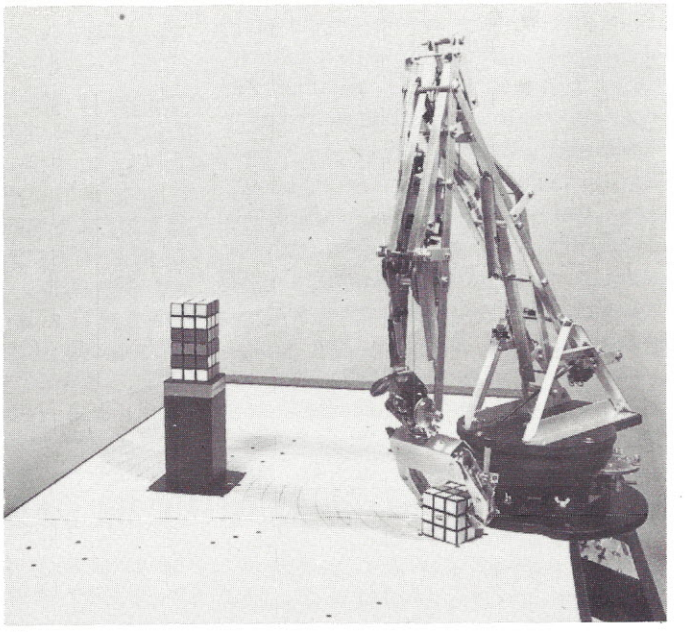

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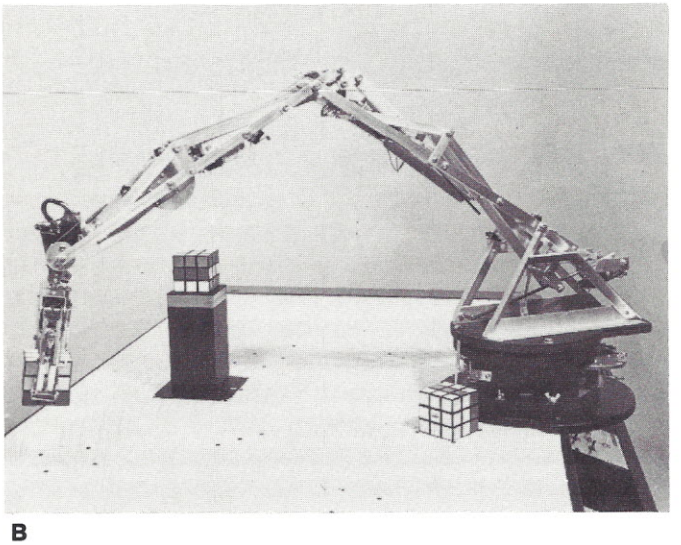
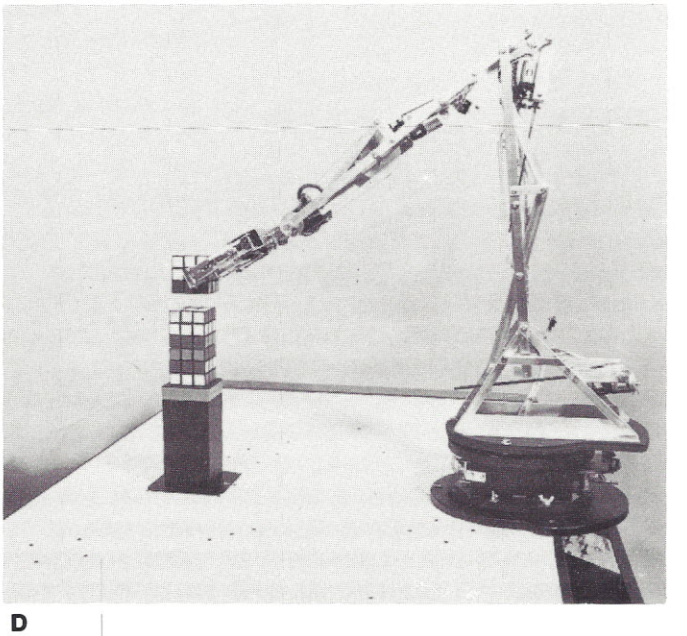


B



D

Photos 12A, B, C, and D. Four configurations during a block-stacking sequence. The blocks are Rubik's cubes. **Photo 12A:** The initial block positions at beginning of sequence, arm in home position. **Photo 12B:** First block already placed, the arm is making a long reach for the second block. **Photo 12C:** Two blocks are already correctly placed, the arm is making an underhand grasp for third block. **Photo 12D:** Placement of third block is almost completed.

of short ones. Even with the capability to monitor all servos simultaneously, the sequence will still have a minimum duration equal to the long move. A six-move sequence will by no means take six times as long as it would with simultaneous feedback monitoring. A more likely estimate in most cases is only perhaps 1.4 to 2.5 times as long. In addition, other constraints may limit simultaneous movements. For example, if there are obstacles in the working area, body rotation must be completed first, else it may be impossible to lower the bicep or forearm without hitting something. In operation, the one-at-a-time sequencing in Armega 33 is not particularly apparent, since there is no perceptible delay between the end of one movement and the beginning of the next.

It is nevertheless true that the ability to move several servomotors at once is a desirable feature. It is high on my list of future refinements. The most obvious approach is to provide individual counter circuits for each servomotor. The host computer would then need only to distribute the desired counts to the individual counter circuits and detect when the counts were completed.

Control Program Development. Developing lengthy and complex control programs for a five-axis arm like Armega 33 can involve a considerable amount of tedious effort, if based purely on "cut and try" methods. The following discussion touches on some of the problems and presents some useful development aids.

When using strictly manual control, it

is difficult to maneuver the gripper pads precisely to a given point even if a visible target is present. If, in addition, the operator wants the hand to be pointing down and vertical to the ground plane, there is really only one set of angles between the elements of the arm which will satisfy this condition. Trying to find this unique combination by hunting around manually for it can be an exasperating experience indeed. Once you find it, you must determine the movements of all the individual arm elements required to get there at will from the home position, *without* a lot of hunting around. Teaching utility programs are often developed for this purpose.

These teaching programs are able to record the individual element movements required to reach the desired position. I have developed a very simple Armega 33 teaching program which uses a combination of both manual and computer control.

After you have manually maneuvered the gripper pads into the desired final position, the computer starts a simple pulse-counting routine. Each arm element is then driven back to the home position through manual control. As each element reaches home, the pulse counting routine is stopped and the servomotor count is recorded. The pulse-counting routine is then set to zero, and restarted for driving the next element to the home position. This procedure produces a set of servomotor feedback counts that can be placed in a control program. Although this type of utility program is useful, it does not eliminate the tedious manual control exercise involved in establishing the final gripper pad position.

The elegant solution which comes to mind at this point is a global set of Cartesian or polar coordinates for the arm's entire *swept volume*. We would also need a set of trigonometric relationships for calculating counts as a function of final position. This type of program is feasible but very complicated.

I developed a more mundane but eminently practical program method for Armega 33. It takes the form of the Simulator Board shown in photo 11. The Simulator Board is accurately constructed as a half-scale physical arm model. Protractors are mounted at the shoulder, elbow, and wrist pitch axes. The joint angles can be read directly from the center lines of all arm element pairs. Stops have also been

Listing 4. The BASIC block-stacking program.

```
10 REM * THIS IS RBT38D (02/12/83). IT IS A GENERAL PURPOSE *
20 REM * PICK-AND-PLACE PROGRAM ORGANIZED BY INDIVIDUAL *
30 REM * ELEMENT PROGRAM MODULES. THE SEQUENCE BEGINS AND *
40 REM * ENDS WITH AN INDEXING ROUTINE *
50 REM * THE DESCRIPTIVE TITLE OF THIS PROGRAM IS: *
60 REM * "STACK THREE BLOCKS" *
200 DEFINT A-Z
399 SQ=1 : E=1 : B=1 : P=1 : H=1 : R=1 : S=1
400 ON SQ GOTO 500,3000,1000,2000,4000,6000,4000,6000,1000,
2000,3000,6000,4000,6000,2000,1000,6000,4000,6000,2000,1000,
3000,6000,4000,6000,2000,1000,3000,6000,4000,6000,1000,2000,
3000,6000,4000,6000,1000,500,7000
500 REM * INDEXING MODULE *
510 CLS : OUT 3,0
520 OUT 3,128
530 GOSUB 10000
540 PRINT @ 274, "INDEXING UNDERWAY"
============================================================
         ( HOMING SEQUENCE OMITTED, SEE LISTING 1 )
============================================================
1000 REM * ELBOW MODULE *
1010 CLS : C1=0 : SW=0
1020 ON E GOTO 1050,1100,1150,1200,1250,1300,1350
1050 OUT 3,196
1055 A=INP(3)
1060 IF A=0 AND SW=1 THEN C1=C1+1 : SW=0 : GOTO 1075
1065 IF A=0 GOTO 1055
1070 IF A<>0 THEN SW=1
1075 IF C1=110 THEN 1085
1080 GOTO 1055
1085 OUT 3,4
1090 GOSUB 11000
1095 OUT 3,0 : GOTO 1800
============================================================
              ( 6 ELBOW MOVEMENTS OMITTED )
============================================================
1800 E=E+1
1810 SQ=SQ+1
1820 GOTO 400
2000 REM * BODY MODULE *
2010 CLS : C1=0 : SW=0
2020 ON B GOTO 2050,2100,2150,2200,2250,2300
2050 OUT 3,65
2055 A=INP(3)
2060 IF A=0 AND SW=1 THEN C1=C1+1 : SW=0 : GOTO 2075
2065 IF A=0 GOTO 2055
2070 IF A<>0 THEN SW=1
2075 IF C1=139 THEN 2085
2080 GOTO 2055
2085 OUT 3,1
2090 GOSUB 10500
2095 OUT 3,0 : GOTO 2800
============================================================
               ( 5 BODY MOVEMENTS OMITTED )
============================================================
2800 B=B+1
2810 SQ=SQ+1
2820 GOTO 400
3000 REM * WRIST PITCH MODULE *
```

Listing 4. Continued from page 30

```
3010 CLS : C1=0 : SW=0
3020 ON P GOTO 3050,3100,3150,3200,3250
3050 OUT 3,72
3055 A=INP(3)
3060 IF A=0 AND SW=1 THEN C1=C1+1 : SW=0 : GOTO 3075
3065 IF A=0 GOTO 3055
3070 IF A<>0 THEN SW=1
3075 IF C1=107 THEN 3085
3080 GOTO 3055
3085 OUT 3,8
3090 GOSUB 11500
3095 OUT 3,0 : GOTO 3800
=========================================================
          ( 4 WRIST PITCH MOVEMENTS OMITTED )
=========================================================
3800 P=P+1
3810 SQ=SQ+1
3820 GOTO 400
4000 REM * HAND MODULE *
4010 CLS : C1=0 : SW=0
4020 ON H GOTO 4050,4100,4150,4200,4250,4300,4350
```

cemented to the protractors to limit the simulator angles to the actual arm movement ranges.

The simulator is very easy to use. The simulated gripper pads are placed at the desired final point and attitude position. The element angles are read directly from the three protractors. The servomotor feedback pulse counts, from the home position to the final position, are read from individual plotted curves of angle vs. count, for each servomotor. This process quickly provides a count value for programming shoulder, elbow, and wrist pitch servomotor movements. Separate curves for body rotation and wrist rotation are used to read the corresponding servo counts for these two elements.

The entire process requires only a few minutes. The initial test run, based on the pulse counts estimated in this way, is usually quite close to a satisfactory sequence. It only remains to tune the program by removing or adding a few units to the counts, here and there, based on the test runs.

Accurate counts alone are not a sufficient foundation upon which to base a control program, however. The programmer must develop a sense for working arc configuration along with a feeling for the possible consequences of arm movement sequences. What is apparently the most straightforward sequence may have to be altered to avoid obstacles in the work area. Even without obstacles, serious arm crashes can result from an improperly

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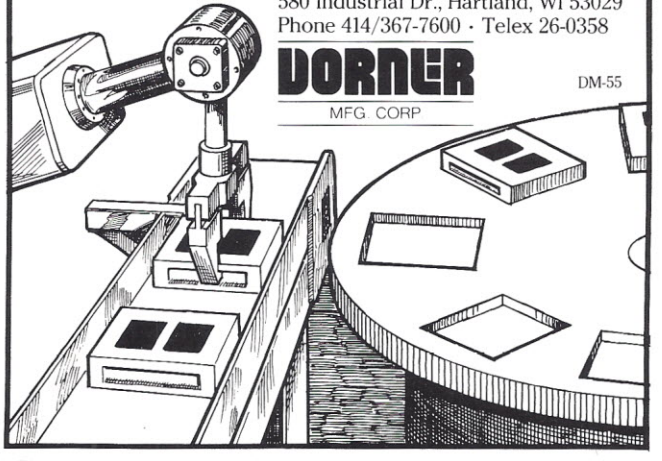

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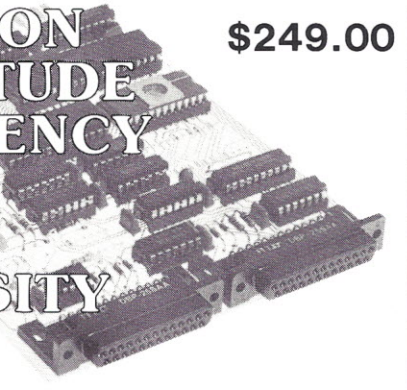

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Circle 22

Listing 4. Continued from page 31

```
4050 OUT 3,224
4055 A=INP(3)
4060 IF A=32 GOTO 4070
4065 GOTO 4055
4070 OUT 3,0 : GOTO 4800
============================================================
              ( 6 HAND MOVEMENTS OMITTED )
============================================================
4800 H=H+1
4810 SQ=SQ+1
4820 GOTO 400
5000 REM * WRIST ROLL MODULE *
6000 REM * SHOULDER MODULE *
6010 CLS : C1=0 : SW=0
6020 ON S GOTO 6050,6100,6150,6200,6250,6300,6350,6400,6450,
6500,6550,6600
6050 OUT 3,130
6055 A=INP(3)
6060 IF A=0 AND SW=1 THEN C1=C1+1 : SW=0 : GOTO 6075
6065 IF A=0 GOTO 6055
6070 IF A<>0 THEN SW=1
6075 IF C1=205 THEN 6085
6080 GOTO 6055
6085 OUT 3,2
6090 GOSUB 11000
6095 OUT 3,0 : GOTO 6800
============================================================
             ( 11 SHOULDER MOVEMENTS OMITTED )
============================================================
6800 S=S+1
6810 SQ=SQ+1
6820 GOTO 400
7000 END
10000 REM * DELAY FOR LATCHING RELAYS *
10010 FOR N=1 TO 985
10020 NEXT N
10030 RETURN
10500 REM * REVERSE PULSE FOR BODY *
10510 FOR N=1 TO 4410
10520 NEXT N
10530 RETURN
11000 REM * REVERSE BRAKING PULSE *
11010 FOR N=1 TO 3860
11020 NEXT N
11030 RETURN
11500 REM * REVERSE PULSE FOR WRIST PITCH *
11510 FOR N=1 TO 5145
11520 NEXT N
11530 RETURN
12000 REM * DELAY FOR READING CRT MESSAGES *
12010 FOR N=1 TO 12850
12020 NEXT N
12030 RETURN
```

designed sequence. Suppose, for example, you desire to grasp an object sitting on the *ground plane* in a position requiring that the arm be at its maximum extension. To reach the object from the home position requires that the base rotate to the correct azimuth, the forearm extend, and the bicep lower to the correct position. If perchance the bicep is lowered *before* the forearm is extended, the hand will crash into the ground plane. Lead screw servos being what they are, this will probably terminate the operation, perhaps for a day or so, while the arm is rebuilt. Fortunately, you soon learn to anticipate and avoid this type of error.

Sample Control Program. I will now outline an example of an Armega 33 control program. The example program comprises an initial homing sequence followed by 37 arm movements and concluded by a final homing sequence. The task to be performed is stacking three blocks on a pedestal rising 6 in. (15 cm) above the ground plane.

Photo 12a shows the Armega 33 arm in the home position along with the initial cube placement. Photo 12b shows the first block already in place and the arm making a long reach for the second block. Photo 12c pictures an underhand grasp for block number three. The final photo, 12d, shows the nearly completed placement of the third block. This exercise is a good workout for the arm. The first cube is at a mid-radius of 18 in. (45.7 cm), the second cube at a long reach of 27 in. (68.6 cm), and the final cube at a radius of only 7 in. (17.8 cm).

In the early Armega 33 programming stages, I discovered that simple and straightforward BASIC programs were preferable to programs which added a lot of pretty text on the screen. The use of arrays and lots of video display messages markedly slowed down execution speed and were eliminated for the most part.

After developing a number of control programs for the arm it became apparent that certain common patterns appeared in all of the programs. A general program shell could be set up to handle any possible sequence of movements.

Listing 4 is an abbreviated version of the control program for the block stacking sequence illustrated in the photo 12 series. The complete program has some 450 lines of code to cover the entire sequence of 37 movements plus a homing sequence both at the beginning and end of the program. In listing 4, only the program lines for the initial movement of each arm element are shown along with a notation of the number of additional movements which have been deleted in order to keep the listing down to a manageable length. All of the impor-

tant features of the program shell, however, have been retained.

The principal features of the general program shell involve the BASIC ON GOTO command along with a series of counter variables, one for the *master sequence* and one for each *element sequence.* In line 399, these seven counter variables are all set to an initial value of 1. The counters are: SQ (Master Sequence), E (Elbow), B (Base), P (Wrist Pitch), H (Hand), R (Wrist Rotation), and S (Shoulder). In line 400 the ON SQ GOTO moves through the entire sequence of steps by calling the appropriate module. Note that line 500 is the homing module, line 1000 the elbow module, line 2000 the body module, etc. These same module line numbers are used in all operating programs written using the shell. Line 400 is always an accurate directory of the complete sequence of arm movements. Each time a movement is completed, SQ is incremented by one, as on line 1810. The program then loops back to line 400, as in line 1820, to pick up the next module.

An exactly parallel scheme is implemented with ON GOTO within each of the modules. Line 1020, for example, lists the line numbers of each of the elbow movements, seven in all. Counter E is incremented after each elbow movement so that the next time the elbow sequence is selected by SQ in line 400, the next elbow movement in the sequence is executed.

Summary. All things considered, Armega 33 meets my original design objectives. It certainly was constructed at low cost compared to other manipulator arms of much smaller size. It has also proved to be an effective test bed for developing and testing arm control software. An overall assessment, however, should consider separately the mechanical features of the arm and the electronics with which it is driven and controlled. With faster servo lead screw pulse counting techniques, together with more computer power and separate counter electronics for each arm element, the mechanical design of the arm is capable of simultaneous element movements, quicker motions and further improvements in resolution.

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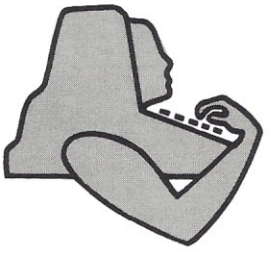

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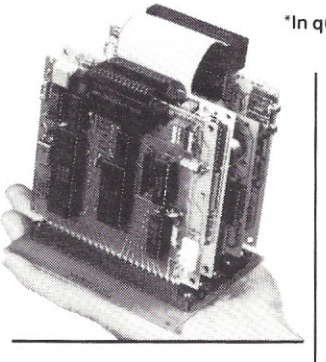

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Computers in the Real World

A Microcontroller System Design

Bob Stewart
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Because of dramatic cost/performance improvements in digital circuitry over the past few years, it is now easy to design a highly sophisticated yet functionally complete computer-command control system. Applications include industrial, commercial, and scientific instrumentation and control. A system can be designed as a toolbox of computer power, allowing the user to dedicate specific capabilities on site, with appropriate programming. A high-level, easy-to-use language can be employed. A number of real-world input/output interfaces can be provided in one compact unit, thereby eliminating extra input/output hardware. The design can include an onboard programming and testing system which removes the need for other development system equipment. The development system and target system are one. All of this can be provided at low cost, which means companies that couldn't afford to purchase computers to control their products or processes a few years ago, can now do so.

Other control systems are available. Programmable timers and controllers work well but are often limited in programming flexibility and power. Standalone data loggers and monitors are also powerful, but the price is high, and control system integration is a problem. Modular designs such as the STD Bus systems have flexibility as well as powerful languages but are sometimes difficult to use. Also, the personal computers that have interface cards or expansion systems are not necessarily designed for the rough treatment they may receive in control situations, and they are generally too expensive to control processes.

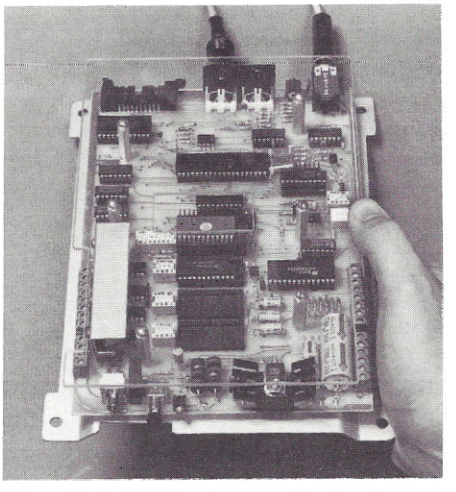

Photo 1. The H.H.S. microcontroller board.

These kinds of problems cause some companies and individuals to custom design their own systems, but development time and costs are often underestimated. When production quantities are low, development costs account for a substantial chunk of the selling price. By the time the design is ready for production, technological advances have often rendered it obsolete, and the dedicated hardware is difficult to change.

Other companies simply do not have the human resources to tackle such a problem. They must rely on turnkey systems from established vendors. The drawback here is that the vendor's system might not directly fill a user's needs, and no mass-marketed hardware/software package can meet everyone's specific needs.

The microcontroller system discussed here provides some answers to these problems. A design by *H.H.S. Microcontrollers* combines the power, flexibility, and friendliness of the personal computers into a system built from the ground up for real-time/real-world acquisition and control.

The following segments cover each part of the design of our microcontroller system. As you will see, many compromises are made, but the objective remains constant—to provide maximum flexibility and maximum power at the lowest possible cost.

Physical Layout. A control system, particularly a mobile one, must be compact. Space at any given site is usually at a premium. The system must also be mounted on or near the devices to be controlled or monitored. Long cable runs between real-world devices and the computer can cause problems for both input and output signals. We decided that a device about the size of a typical dictionary would be a good compromise between a smaller system that would have fewer capabilities and a larger system that might restrict field placement. Further advances in technology may allow smaller systems.

To keep costs low, the major components must fit on a single board. We designed a semi-enclosed mounting system to provide some physical protection. A shielded or protected enclosure was not added so that the system will fit into existing enclosures.

Power Supply. An onboard power supply is a necessity. External supplies add to the total system cost and raise the possibility of designing another enclosure system.

The control system must be able to obtain power from several sources. AC lines are certainly one source, but battery power must also be considered for remote or

mobile operations. The voltage selections were fairly easy, as they follow the design of existing equipment.

The H.H.S. design accepts inputs from 12 to 18 VDC or 12 to 24 VAC. This allows the controller to draw power in several forms including 12 V batteries, a variety of low-cost 120 VAC to DC battery eliminators (plug mount types used on calculators etc.), 120 VAC transformers (12 and 24 V), and 12 or 24 V control supplies in existing equipment. Extensive use of the new low-power CMOS (complimentary metal-oxide semiconductor) integrated circuit chips allows an unexpanded power consumption low enough to maintain adequate battery life if necessary.

The power supply output must obviously include the regulated 5 V source for the onboard logic circuits. Unlike some personal computers, the H.H.S. controller requires other voltages. Precision sources for analog conversion, excitation for transducers, and computer communication protocols are needed. Extra capacity on all ranges enables certain user circuits such as LEDs or displays to be directly connected. When the user must provide an extra power source for these functions, costs increase. It is not necessary to serve all applications however. Larger current DC devices such as stepper motors or servomotors would need, and should have, separate power supplies.

Although we considered a switching-type power supply, a traditional linear regulator was selected. The major drawback to the switcher was noise. Since noisy AC lines would be present on the board anyway, complications arising from additional interference might affect layout and testing. The power circuit would require a separate subenclosure.

Our design includes the accessible precision voltages mentioned. Some of the voltages may be preadjusted by the user when connecting external real-world devices and sensors.

Processor. The major criteria used to select the microprocessor were execution speed, real-time capabilities, memory efficiency and cost. With a 4 MHz clock speed, an onboard interrupt controller, a clock timer, a large register file and widely recognized Z80, Z8000 instruction set similarities, the Zilog Z8™ family of microcomputers filled the bill. The serial port and read-only memory space aboard the Z8 chip further simplified the design of external circuitry.

The Z8 series was designed expressly for use in control applications. Yet the instruction set and ALU (Arithmetic and Logic Unit) are powerful enough to implement a high-level interpreter. Also the multichannel hierarchical interrupt structure gives the programmer more flexibility when dealing with real-time events affecting peripherals, commonly encountered in control programming.

Memory. The most important consideration for memory on this type of field-programmed control system is flexibility, not size. Each application may have different memory requirements. It is almost impossible to predict needs until the program is written. Fortunately the JEDEC standard for memory configurations meets these criteria. These bytewide (8 bit) 28-pin sockets accept read-only memory, EPROMS, EEPROMS, and programmable memory.

When selecting memory size, the designers wrote a number of actual control programs in BASIC and Assembly Language on a prototype. The results showed that with full use of the interpreter and onboard operating system most programs took between 2 Kbytes and 6 Kbytes of memory. If this surprises you, remember that in most business or personal computing applications, memory is primarily filled with data. Character strings, variables, constants and memory-mapped video bytes use lots of programmable memory. Although data storage is important for the controller, it is the program that is usually of primary concern. To allow plenty of room for growth, however, we decided on a relatively large 16 Kbyte user memory block. This allows room for adding custom operating systems and other languages later.

Input/Output. A control system should have computer-compatible input/output that allows it to communicate with as many devices as possible. Although IEEE488 (HPIB) and proprietary data highway type interfaces are popular, most microcomputing equipment is geared for simple serial or parallel communication interfaces. Pin and signal protocols are usually for RS-232 or the Centronics™ standard. Our selection of both these interfaces allows the exchange of data with hundreds of devices including host computers, slave units, modems, printers, plotters, graphic tablets, digital recorders and disk systems.

Low-cost offline data storage is also needed. The H.H.S. design uses a cassette system interface. The tape system is primarily a data recorder for a remote acquisition system and it has a good cost/performance ratio.

The real-world (noncomputer level) input/output interfaces are the heart of the system. It is these interfaces that set the microcontroller system apart from single-board computer devices. The interfaces should be flexible enough to allow a variety of uses in a number of applications. They should not try to be everything to everybody.

We had to analyze the noncomputer devices that might be involved in an integrated control task. This was a formidable undertaking. There are thousands of devices, some electrical and some electronic, that could be part of a system. Recognizing groups of devices was the best we could do. Once the groups were acknowledged, those with common interface protocols were put together. A weighting system was employed to determine if a particular group of devices was numerically more prevalent than another. This was also difficult due to lack of statistics. The question, of course, is how many and what kind of ports should the controller have to serve the broadest needs? All of these factors have to be considered with an eye to final cost and board space.

After much deliberation, the following ports were included in the system.

- Four 120 VAC solid-state relays with a capacity of about 4 A. The need to control lights, motors, heaters and other AC devices is extensive in industrial, commercial and scientific applications. Cost and space prohibited us from adding more of these useful ports.
- Eight channels of 8-bit A/D conversion inputs. Most real-world sensors currently available (including temperature, pressure, flow, sound, and light) output variations in voltage or current. This must be converted to a binary value to enable processing. Again both the number and frequency of applications in this area are high.
- As many as 30 low-level digital (on or off) input or output channels. Switch inputs, keyboards, LED indicators, relays, microswitches and all sorts of low-

voltage computer-oriented devices are available and are used in many control situations.

- Four channels of high-level isolated digital input (120 VAC). Primarily useful for rough service in electrically noisy locations in factories where low-level digital inputs may be unreliable.

Selecting these ports was easy. One glance at the statistics shows why these interfaces were included. But making other capability selections proved more difficult.

A lack of industry standards is one limiting factor. Compatibility with external devices is a problem in all areas, but especially troublesome in motion and axis control. For example, interfaces between computer and encoder and computer and motor driver boards (stepper or servo) often vary from manufacturer to manufacturer.

Another problem is the reliance on traditional designs. Engineers often design computers that are compatible with existing analog (linear) controllers. They first consider the external hardware configurations (machinery and sensors) to be used. Then an attempt is made to find computer interfaces to match the requirements of these devices. Finally, a computer is selected and a program is written so that the user can gain access to the devices. However, research studies show the most effective use of computer control is realized when designers review software and hardware capabilities first. This approach, working outward from the programming model, produces an improved and efficient system. Fewer control lines are needed and input and output can be simplified.

The following ports, designed to allow modification, are included to serve specific uses.

- One or two channels of DC solid-state relays. This is necessary because the AC power control (Triacs) cannot be used for DC. Preliminary surveys showed a more limited use for direct DC control than previously expected. DC servocontrol was one area of application, although alternative methods of control could be devised. A number of other external circuits were considered as possible uses for this port.
- One channel of digital-to-analog conversion (DAC) or Pulse Width Modulator (PWM) output. A number of available control devices still require variable voltage input. A number of user-constructed external circuits may also need this output protocol.

All input ports also have a hardware accessible line connected to the interrupt controller.

Expansion. A microcontrol system should be expandable in at least two ways: each machine should allow onboard expansion and the addition of new capabilities, ports, and memory. Although not as flexible as bus-system computers, the H.H.S. expansion header permits at least one expansion board per controller. This means memory can be expanded up to 80 Kbytes or a multiprocessing system can be used. The system must also accommodate additional controllers linked through a host, which can also be a controller. This works in cases where a single system has too many I/O ports. Our design enables the RS-232 signals to be controlled so that the serial interface can operate as a host-slave link when properly controlled by user software.

Language. Human interaction is of course important. As many people as possible must be able to work with the control system. Existing control languages range from simple ladder diagram programs (Texas Instruments' 5 TI, for example) to powerful Lisp and Forth interpreters. Custom-designed, menu-driven authoring systems are used. In systems that have no language at all, programming is accomplished with complex and expensive development systems that use custom software to produce complicated machine code.

After considering the options, our designers chose BASIC. Purists may correctly argue that this interpreter is not as well adapted to a control environment. However, the established base of computers with BASIC contained in ROM suggests that many people are familiar with this language. It is also possible to do as much with BASIC as any other language, although some constructs may be more awkward and slower.

Fortunately, the processor selected for the application is available with a limited control BASIC in the onboard read-only memory, further simplifying the design.

Design Specifications. It is unnecessary to make this toolbox control system applicable to every design. Aerospace applications, for example, must fulfill technical service orders or military specifications. Obviously, an inhouse dedicated design would be preferable. By the same token, an overly expensive design reduces the attractiveness of the system for general use. But standards for hardware and components should be adhered to in order to insure operation in less than ideal circumstances. When selecting components, outdoor, industrial environment, and some hazardous location specifications were considered.

It is unnecessary to make the overall electrical performance equal the best devices on the market. Precision data acquisition systems are available that have better resolution, faster sampling, and more capable signal conditioning than the H.H.S. system. If the most stringent criteria must be met for a certain application, the more precise (and more expensive) system will be needed. Occasionally users and applications engineers request equipment that is more sensitive than actually needed for a particular application. But, in many cases, the parameters of the general-purpose system are more than sufficient.

Program Development. Since much time and money is spent programming applications, the controller should be as easy to program as possible.

Program reproduction and storage is a factor. Our design gives the user several options. For short-term storage, while the system is being developed, programmers can use battery-backed programmable memory, the cassette system, or, if using a host system, the host disk. For permanent, nonvolatile, nonmechanical storage, EEPROMS and EPROMS are probably most reliable. EEPROMS are especially attractive because they require no external hardware to program or erase. Programming ultraviolet EPROMS requires some external hardware. We chose these options because programming is usually a one-time event and giving EPROM-burning capacity to all systems simply isn't cost-effective.

Another factor to consider is the physical environment at the development station. Users should be able to attach peripherals to the system while it is being tested, enabling observation of the devices under operating rather than simulation conditions. Our small, compact and field-programmable unit can handle this.

Figure 1 shows the general environment associated with the control system. The host computer or terminal is shown at the top. It is normally used only during pro-

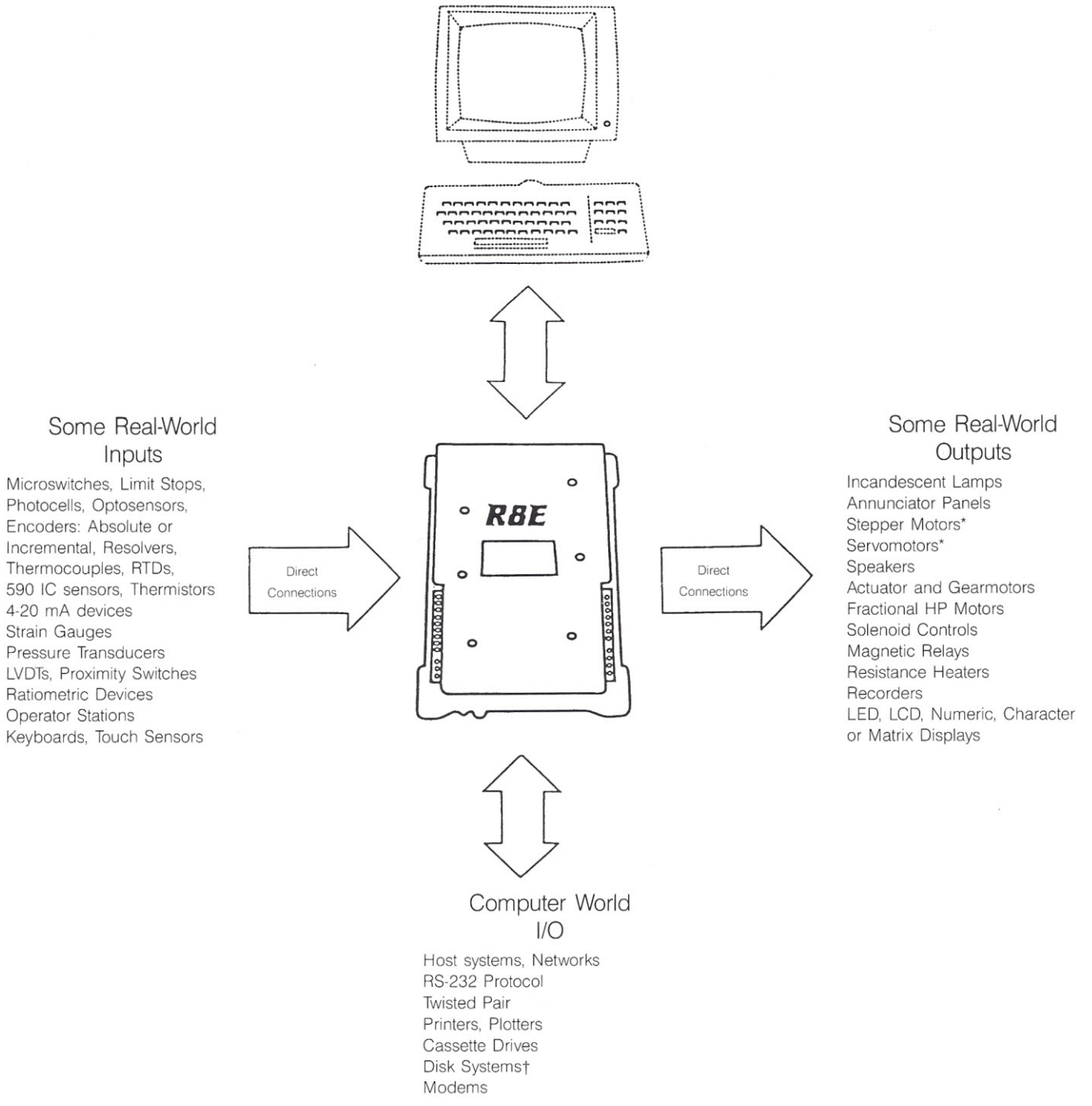

Figure 1. The general development environment associated with the control system. The host computer or terminal is shown at the top.

gramming and development, after which the controller is a standalone device.

We foresee these small yet powerful systems being used in many kinds of applications. Localized, programmable control or timing can have a higher level of sophistication. Data logging and monitoring systems can have the control capabilities they need and can be better suited to field mounting, while costing less. Process control, including robotics, can have on-site intelligence while being tied to a host or network for overall supervision. And experimentalists and scientists can easily use their personal computers, not only in the office but in the field.□

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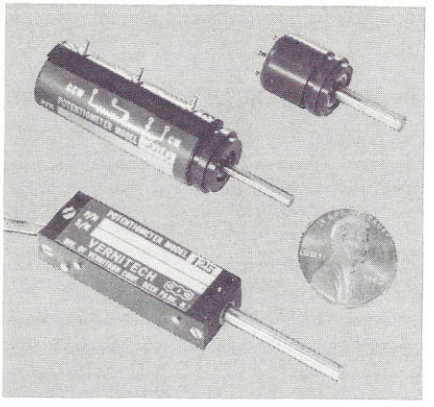

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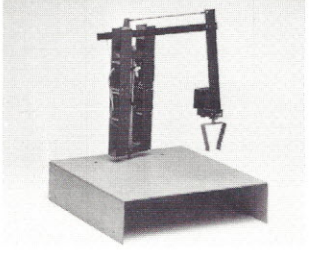

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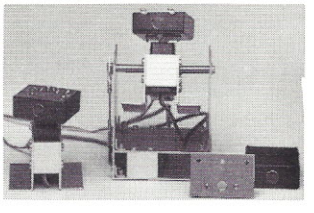

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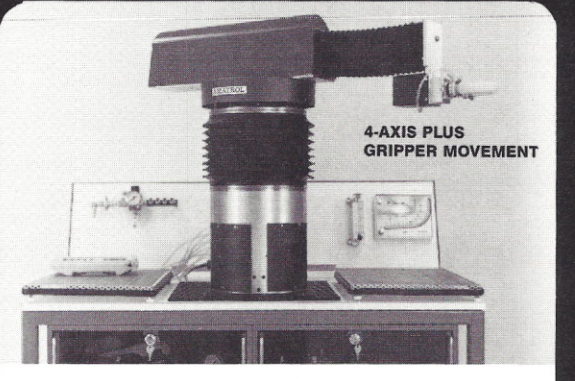

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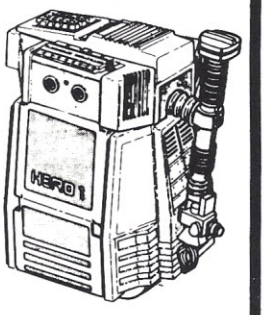

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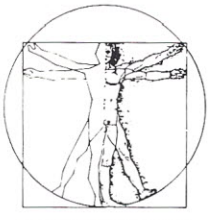

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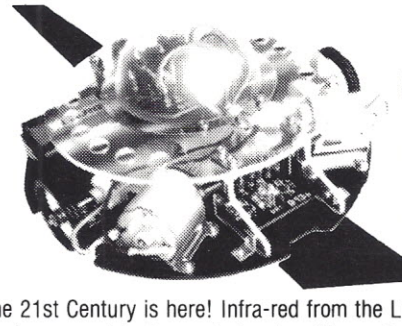

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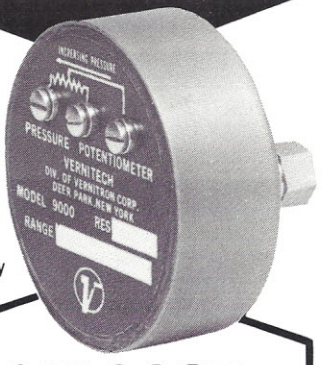

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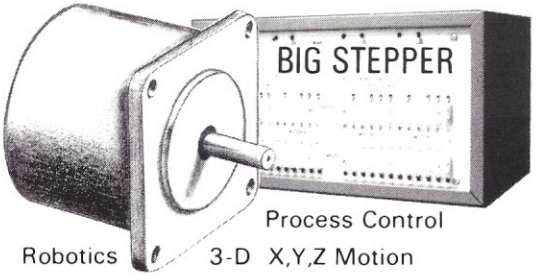

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Editorial *Continued from page 4*

CP/M provided a base from which other software packages could be developed. Programmers could experiment with software packages and know that other programmers who also had CP/M operating systems could use their programs. Not that CP/M was the perfect answer. It had (and still has) some strange quirks. However, it is such a well-known and well-understood piece of software, that people have come to know and understand its quirks. In the balance, the advantage is a small control program which can control terminals, paper tape readers and punches, disks, and printers.

Although there are relatively few operating systems in existence today, there is a vast variety of programming languages. Certain languages are better suited for certain jobs. And, as always, particular programmers have their pet languages.

Extrapolating this sequence of events to the burgeoning world of experimental robots, it would appear that what is needed to spur growth is not a standard language that tries to be all things for all people, but a standard *operating system* which provides application developers with a base on which to create their own robot control languages, as well as to use existing programming languages. At present, the only experimental robot manufacturer offering this capability is the Marvin robot from Iowa Precision Robotics, Ltd. Marvin is provided with a M68000 brain which can run CP/M 68K.

CP/M, in all its diverse forms, is probably an excellent choice for a first-try robot operating system. Although the standard version is not designed for real-time control, it does have some very definite benefits. CP/M is a small operating system (very important in limited-memory robot systems). Since it is also one of the most popular microcomputer operating systems, many experimentalists already have a CP/M-based system which can be used for program development. Since many languages are already designed to run on a CP/M operating system, robot programmers would not be limited to any one language; they could used the language most appropriate for the task or develop their own. Forth, Lisp, Prolog, BASIC, FORTRAN, Pascal, C, Assembly, and even COBOL programmers could use their favorite language.

A recent development from AMI, a semiconductor manufacturer, will also affect a designer's decision to use CP/M. AMI has introduced a Z80 microprocessor with onboard read-only memory. One version of the chip contains CP/M in the onboard read-only memory. This chip would be an excellent choice for the central brain of a robot control system.

Oh, yes. I can already hear the case against CP/M. It has no real-time programming facilities. It has no standard interface to motors or sensory devices.

I am not suggesting that CP/M will be the answer to all our robot programming needs. What I am suggesting is that we shouldn't reinvent the wheel but use the tools provided us by our robots' predecessors, the microcomputers. Someday, perhaps soon, someone will develop an inexpensive, small, real-time operating system which understands motors, sensors, and concurrent processes. Until then, let's get the robot revolution moving with the tools which already stand before us.

New Products

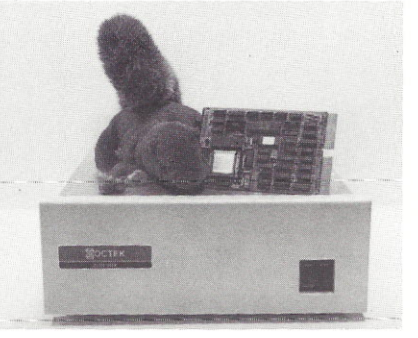
Robot System Inserts Nonstandard Components

The Chad ECA 101 robot system economically eliminates the costly, time-consuming hand insertion of irregularly-shaped components, a process which has long been required in conjunction with the automated insertion of standard chips. The ECA 101 is able to compensate for variations in the body-to-lead orientation of nonstandard parts. The robot can handle parts from 0 to 1.5 in. in size and place them randomly with spacing as little as 0.05 in. between components. This placement is accomplished without the need to change jaws or add exotic lead-gripping fingers. On an average board, 15 or more different components can be handled by the Chad end effector, depending on the feeding mechanism arrangement. The average placement time is 2.5 seconds from grip to release, with a repeatability of 0.001 in.

The Chad ECA 101 is housed in a sturdy steel base, which maintains the precise tolerances of the system. The entire workcell measures 46 by 53 in. standard and is available in an 84 by 84 in. configuration. The system includes the Chad end effector, Seiko RT-3000 DC Servo Robot, software and mounting base.

For additional information, contact: Dean Williams, Chad Industries, 1060-K North Batavia St., Orange, CA 92667, telephone (714) 997-4350. Circle 40

Machine Vision for Harsh Environments



Applications in harsh or contaminated environments that could benefit from machine vision are now feasible. Octek announces that its 20/20 TASK (Target Application System) is now available with Squirrel, a bubble-memory board for nonvolatile mass memory storage.

Squirrel can be programmed from a floppy disk unit or a direct downloading from an Octek 20/20 Vision Development System. Storage capacity is 128 Kbytes standard or 512 Kbytes if larger data storage is required. Squirrel guarantees that stored programs are not affected by line transients or power outages.

An optional NEMA 12 enclosure provides additional industrial protection for tough in-plant installations.

20/20 TASKs with Squirrel bubble memory are currently being shipped. Single quantity price is $18,950 for 128 Kbytes and $22,900 for 512 Kbytes. OEM prices are available in quantities of ten or more.

For more information, contact: Octek, Inc., 7 Corporate Place, Burlington, MA 01803, telephone (617) 273-0851.

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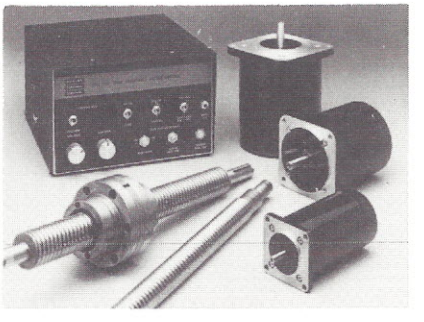
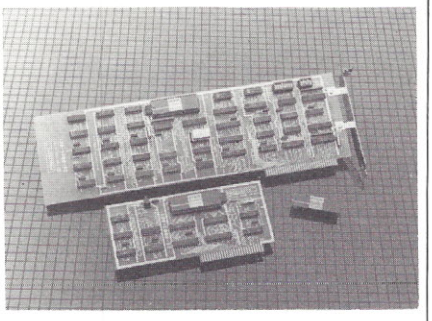


New Products



Proximity Boards

Proximity Technology, Inc. has introduced a revolutionary chip which brings the world of computer technology one step closer to human intelligence.

The function and architecture of the PF474 are targeted at the rapidly growing areas of office automation, data base machines, robotics, automatic speech recognition, user friendly systems, and artificial intelligence in general. The term *Fifth Generation* is increasingly being used to describe systems that are expert in these areas.

The comparison of one string of symbols to another is the heart of many computer applications. Often, it is important to identify the degree of similarity between these strings, not just an exact match. The PF474 can compare any string of characters with other strings in a text or data base at a speed of 30,000 28-character strings per second. The chip also evaluates the degree of similarity with a numerical rating and keeps a table of the 16 best matches found. Since the comparison speed is a linear function of string length, 40-character strings could be processed at a speed of 15,000 comparisons per second.

The PF474 is an important new tool available to systems designers and problem solvers. Its creative application will deliver new and exciting benefits to users of computers and other electronic devices.

Proximity has designed interface boards and development software tools for the IBM PC and compatibles, Apple II series and compatibles, and the Q-Bus. The chip is also available separately for system designers.

For more information, contact: Mindy Kimmelman, Proximity Technology, Inc., 3511 NE 22nd Ave., Ft. Lauderdale, FL 33308, telephone (305) 566-3511.

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High-Performance Stepper Motor Driver/Controller

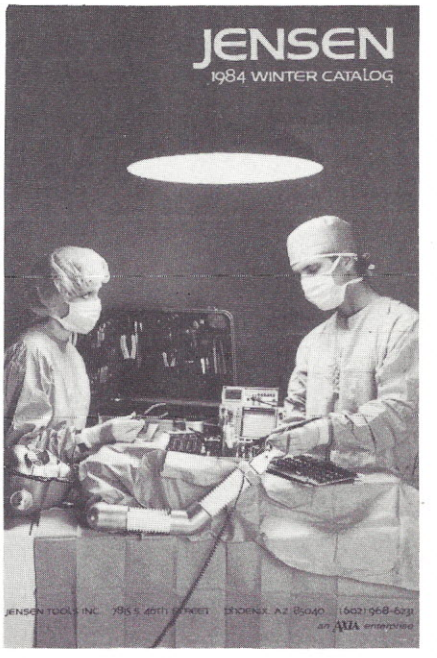
Cyberpak is offering the High Stepper Two, the first in a series of high-performance stepper motor controllers. The HS-2 controller is a single card capable of driving two stepper motors and connecting to any personal computer with a parallel port. The HS-2 has many features that differentiate it from other stepper motor controllers in its price class.

Like other stepper motor interface cards, the HS-2 is completely opto-isolated from the computer, connects to any 8-bit parallel port, and will drive most common stepper motors (up to 2 A per phase) used in education, robotics, and control applications.

The HS-2 offers significant advantages over other low-cost controllers. The HS-2 allows use of bipolar as well as unipolar motors. Bipolar motors deliver a 25 to 40 percent increase in torque over unipolar motors. Eight and six-wire motors can be wired for either arrangement. The HS-2 also uses switched (chopper) mode drivers, which regulate current through the motor coils. This feature further increases torque and yields a much higher maximum step rate than other low-cost controllers. The HS-2 allows the user to adjust current for each of the two motors independently. Full, half-step, and wave drive, plus an inhibit mode (drive power removed from the motor) can be computer-selected.

The HS-2 controller/driver card is available in both single motor ($99) and dual motor ($139) drive versions. The single-drive version can be upgraded to the dual-driver version.

Further specifications on the High Stepper series are available from Cyberpak, PO Box 38, Brookfield, IL 60513, telephone (312) 387-0802. Circle 44



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Jensen Tools, Inc. has published their newest catalog of precision tools. The 80-page catalog contains more than 1,000 tools of interest to field engineers, technicians, computer and telecommunications service persons, and electronic and robotic experimentalists.

Major tool categories are: test equipment, microtools, soldering equipment, tweezers, screwdrivers, cutters, drafting supplies, power tools, computer accessories, circuit board equipment, and miscellaneous. Also included are many new products from Jensen, plus page after page of service kits and tool cases for electronic specialists and technicians.

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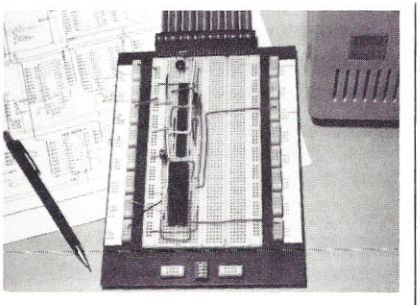
Computer Prototyping Board

The eZ Board is a solderless experimenter system which provides a time-saving and convenient method for building experimental add-ons to personal computers.

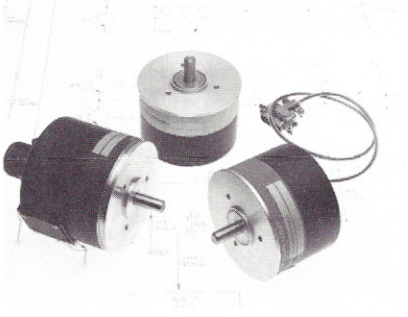
Features include a high-quality glass epoxy printed circuit board mounted with a set of solderless breadboarding units for building circuits. Four separate distribution buses with 50 tie-points each can be used for power, ground, clock lines, reset commands, and more. An array of tie-point blocks from which each pin of the computer's bus system (I/O channel) is clearly labelled for quick identification and is easily accessible. A four-position DIP switch is mounted on the board. Each switch position connects to a set of tie-point block sockets on either side, to aid in the development and analysis of experimental circuits. A flat ribbon cable connects the board to the computer's bus expansion slot.



The breadboarding area consists of 1460 tie-points with a capacity of 16, 14-pin DIPs. Components with lead diameters up to 0.032 in. simply plug in and are connected with ordinary solid hookup wire. The board is useful for R&D engineers, experimentalists, and students who wish to build their own computer interfaces. The eZ Board aids in understanding the operation of a computer's bus system and provides the function of each output terminal of the bus for use in developing add-on circuits for interfacing to a computer.

Models IPC, APC, and CPC are available for IBM-PC, Apple, and Commodore computers. Models for other computers will be introduced during 1984. Retail price for the entire system, including cable and connectors, is $174.95 plus $5.00 shipping. International patents are pending.

For further information, contact: Mr. Rahim Sabadia, S.E. Corp., PO Box 1132, Yorba Linda, California 92686, telephone (714) 630-9335. Circle 49



High-Resolution Encoder

Teledyne Gurley has introduced the Series 835, an optical incremental encoder designed for high resolution applications.

The 3.5 in. diameter encoder features LED illumination, dual reading heads for higher accuracy, a ⅜ in. shaft, labyrinth shaft seal, and several electronics and mounting options.

Integral electronics provide a variety of outputs including up/down pulses up to 216,000 pulses per revolution (6 arcsec resolution), while optional external electronics can generate up to 432,000 pulses per revolution (3 arcsec resolution).

For more information, contact: Teledyne Gurley, 514 Fulton St., Troy, NY 12181, telephone (518) 272-6300. Circle 50

Proportional Electronically-Controlled Pneumatic Valves

The Series 60 pneumatic valves from Schwien and Son are controlled by a signal which is less than 1/50 W. The valves are actually composed of two regulators, one being a supply regulator and the other an electronically-controlled pneumatic amplifier. This combination facilitates connection and saves space. These valves are widely used in altitude (absolute) and airspeed (differential) simulation equipment, performing to 0.001 in. Hg. With a closed loop servo system (incorporating a frictionless pressure transducer) any finite signal change, however small, produces a proportional pressure change.

Closed loop response can be made flat in pressure to 10 Hz. Standard pressure range is from nearly 0 psia to 70 psia, with an optional range to 500 psia. The flow rate of any of these valves is 1 SCFM. Schwien and Son provides a custom design service to tailor components to user specifications.

For more information, contact: Schwien and Son, 293 Ventnor Avenue, Aspen, CO 81611, telephone (303) 925-5670.

Circle 51

New Products

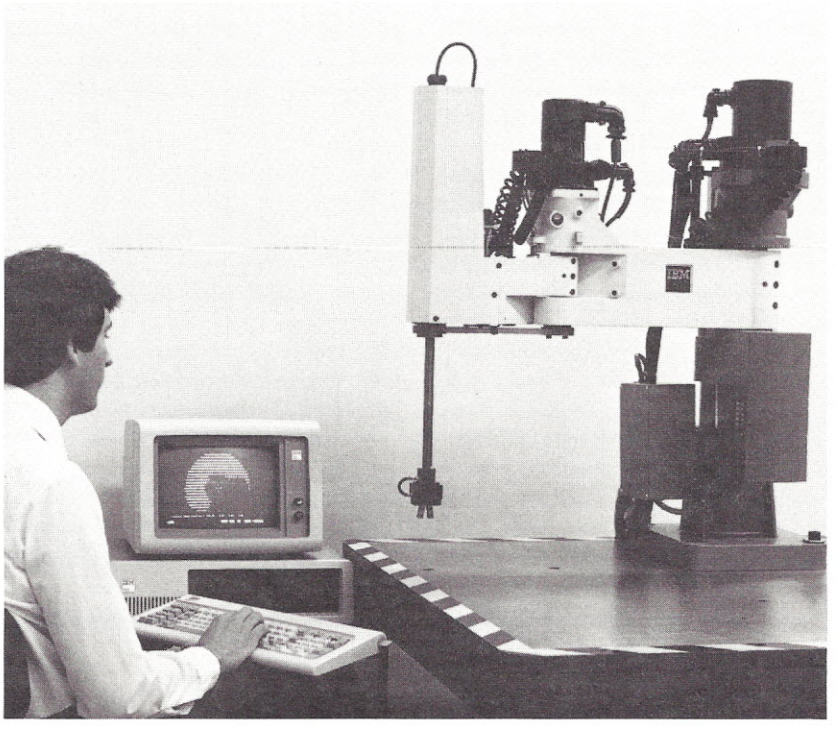
New IBM Robot

IBM has introduced the IBM 7545 Manufacturing System, a programmable, electric-drive system designed for a wide range of electromechanical assembly, fabrication, and material-handling tasks. The new system complements IBM's lowest-priced robotic system, the IBM 7535, adding a continuously variable vertical axis, a longer vertical range, and a more powerful roll motor.

The IBM 7545 features four servocontrolled axes capable of moving the robotic arm in four directions with a payload of nearly 22 lbs (10 kg). The vertical axis enables the tooling to be stopped at any point along its 9.8 in. (250 mm) vertical range. The new, servocontrolled roll motor produces five times more torque than the IBM 7535 roll motor.

The system is controlled by a microprocessor-based unit that can store up to five distinct, multiple-point routines or programs to a maximum of 24,000 bytes of memory.

Application programs for the IBM 7545 are developed on an IBM Personal Computer using an enhanced version of IBM's entry-level robotic programming language AML/Entry Version 3.



AML/Entry Version 3 is priced at $3,000. Deliveries of the IBM 7545 are expected to begin in the first quarter of 1984. The system is priced at $36,000.

For more information, contact: International Business Machines, Corp., 1000 NW 51st St., Boca Raton, FL 33432, telephone (305) 998-3259. Circle 47

Marvin Educational Robot

Marvin Mark I is a sophisticated educational robot. It is designed as a teaching aid for industry, technical schools, universities, and experimentalists. Marvin can move around a room, talk with a synthesized voice, move its head, use sonar ranging, and use two six-axis arms that can be programmed to work simultaneously.

The Mark I can be operated as an independent blackout-proof personal/business computer with its onboard 3.5 in. high-density floppy disk drive. Marvin's computer brain is a Motorola 68000 microprocessor with a 16-bit data path and a 24-bit address bus. The basic memory configuration is 128 Kbytes of programmable memory, expandable to 512 Kbytes. A six-slot S-100 bus card cage allows you to add a variety of commercially available S-100 compatible cards.

The Marvin operating system is ERPL (Educational Robot Programming Language) and will support CP/M 68K or other user-supplied 68000 operating systems. The ERPL programming language, monitor, movement table library, full test and demonstration package, diagnostic software, text-to-speech program, servocontrol package, and ultrasonic ranging software are provided with the basic Marvin.

The Mark I has a humanoid torso with a shatterproof vacuum-molded body skin. Under the skin is an aircraft aluminum chassis containing high-quality machined parts to give the Mark I a long life span.

For more information, contact: Iowa Precision Robotics, Ltd., 908-10th St., Milford, IA 51351, telephone (712) 338-2047. Circle 48

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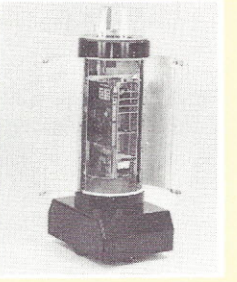
1984 ROBOTICS AGE PRODUCT GUIDE

Robotics Age Product Guide:

A Sourcebook for Educators & Experimentalists



Sentry Robots. Aids for the Disabled. Voice Control. Artificial Intelligence. These are the buzz words of the eighties. The words of an exciting, new world.

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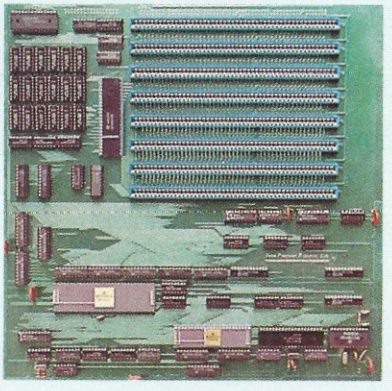
MARVIN MARK I

The Most Sophisticated Personal/Educational Robot Available

Single Board Computer/ Motherboard. Processor - Motorola® M68000 16 brf microprocessor System Memory - 128K bytes RAM expandable to 512K byte on board, expandable to 8M byte by S-100 board ROM up to 16K bytes System 10 2-RS232 serial ports one-parallel port. These are for communication with the outside world, internal communications between servos and computer are taken care of directly.



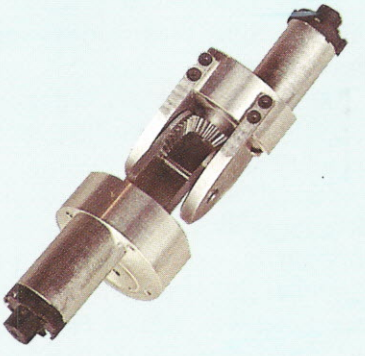
BRAINS

Expansion Bus - 8 slot S-100/EEE-696 expansion bus. Intelligent Servo Controller - Resident on the expansion bus is one S-100 card with 16-full 4 quadrant power MOSFET pulse width modulated servo controllers with axis feedback and auto refresh.
This Iowa Precision Robotics Ltd. Model 68-100 computer supports CP/M® 68K and Forth operating systems. It is also used in our industrial Robot Controller where it meets exacting requirements.

BEAUTY

Anthropomorphic design sculptured body skin adds a finishing touch to the fully machined aluminum inner structure.

Two arms, each with: Axis One: Shoulder is powered thru 135°. The motion you use while bowling. Axis Two: Shoulder is powered thru 105°. The motion you use doing jumping jacks. Axis Three: Upper arm is powered thru 135° of rotation The motion you use while arm wrestling. Axis Four: Elbow is powered thru 115°. Axis Five: Wrist is powered thru 90°. Axis Six: Gripper opens up to 2½ inches and closes down to zero. All arm servos are powerful enough to enable 'MARVIN' handling a minimum five pounds load in each gripper. (A six pack of your favorite beverage weighs approx. 4½ lbs.)
In addition to the 12 arm axes, 'MARVIN' has: Neck is powered thru 180° rotation. Waist is powered from straight up to 50° forward. This enables him to reach the floor with his grippers.



BRAWN

Drive Wheels: Each drive wheel is an individual servo to enable directional control. His maximum rate of forward speed is 50 inches per second and he has enough power to climb a 10° incline.

The MARVIN MARK I is ready NOW! We would like to cordially invite you to see MARVIN MARK I at the International Personal Robot Congress and Exposition, April 13th thru the 15th at Albuquerque Convention Center, Albuquerque, New Mexico. This will be a unique opportunity to research the educational robot market in one location. We are positive when you see MARVIN MARK I and compare his advantages to other personal robots you will want to take him home.
MARVIN MARK I has many outstanding features that set him apart from all other educational robots.

1. 68000 CPU based on board computer/state of the art.
2. S-100 Expansion Bus-a standard feature.
3. CP/M compatable.
4. Two 6 axes Arms - 5 lbs. payload per arm.
5. Simultaneous use of ALL Axes - allows both arms to work on coordinated tasks.
6. Variable speed and direction on ALL axes.
7. Park MARVIN MARK I anywhere and you have a mobile, blackout proof, personal computer with a disk drive and more capabilities than most business computers.
8. The list goes on and on.

The best news is MARVIN MARK I's price! $5,995.00! MARVIN MARK I cost less than comparable business computers with the same capabilities and you get the state of the art in educational robots, MARVIN MARK I as a bonus!
Order today to avoid delivery delays as orders are piling up and 1984 production is limited. A color brochure is available for more information.

Iowa Precision Robotics, Ltd.

908 10th Street, Milford, Iowa 51351
Phone: 712/338-2047 or 712/338-2349
Circle 11